FEMA Benefit-Cost Analysis Reengineering (BCAR)

Tornado Safe Room Module

Methodology Report

Version 4.5

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Contents

Section One: Introduction

1.1 Background

The Tornado Safe Room Module provides a methodology for determining life safety benefits (injury and death prevention) from tornado safe rooms within the updated Benefit Cost Analysis (BCA) software. This module is an update to the Benefit Cost Analysis (BCA) software included in the 1st Edition (July 2000) of FEMA 361, *Design and Construction Guidance for Community Shelters* (FEMA 361). The original software focused on the reduction of injuries and deaths from safe rooms for tornados and hurricanes. Beginning in 2007, in parallel to revisions to FEMA 361, FEMA initiated a redesign of all BCA software associated with their grant programs, including flooding, earthquakes, hurricane winds, and tornadoes. The decision was made by FEMA to develop new BCA software for life safety benefits of safe rooms with separate modules for tornado and hurricane hazards. As the new Tornado Safe Room and Hurricane Safe Room Modules software are finalized, they will be used in place of the original safe room (shelter) BCA software.

This document provides detailed information on the Tornado Safe Room Module methodology. The following sections of this document will describe the methods used for BCA calculations. Specifically, sections will detail the following:

- Overall Methodology
- Project costs
- Project benefits, based on:
    - Probability of tornado events
    - Probability of injury and death due to tornado events
    - Costs associated with injury or death
    - Safe Room occupancy

This methodology was developed based on the input of an Expert Panel (detailed in Appendix A) consisting of experts on tornado and life safety issues.

Section Two: Overall Methodology

2.1 Background

The Tornado Module calculates safe room benefits based solely on the life-safety benefits of the mitigation project. The governing equations used for tornado safe room BCA are similar to other hazards, where benefits are calculated avoided losses, in this case avoided injuries and deaths. These equations will be detailed in this section of the document.

2.2 Benefit Cost Analysis Equations

Cost effectiveness for a mitigation project can be expressed as either the Benefit-Cost Ratio (BCR) or the Net Benefits.

$$BCR = B(Project) / C(Project) \qquad (1)$$

Where:

B(Project) = Total benefits of the hazard mitigation project.

C(Project) = Total costs of the hazard mitigation project.

When the BCR is greater than or equal to 1.0, then the project is considered cost effective.

$$Net\ Benefits = B(Project) - C(Project) \qquad (2)$$

When the Net Benefits are greater than or equal to zero, then the project is also considered cost effective.

Since benefits and costs may be calculated based on a combination of one-time and annual values, a common basis is needed for B(Project) and C(Project). Typically, this is done using an expected annual value, such as the Expected Annual Benefits (EAB):

2.3 Benefit Equations

$$EAB = EAD(Before) - EAD(After) \qquad (4)$$

Where:

EAD(Before) = Expected Annual Damages before mitigation, based on injuries and deaths (in dollars).

EAD(After) = Expected Annual Damages after mitigation, based on injuries and deaths (in dollars).

For the BCR equation, EAB and EAC can be used directly in place of B(Project) and C(Project) to calculate BCR. In the Net Benefits equations, use of EAB and EAC would result in Expected Annual Net Benefits. EAB and EAC could each be converted to a single present year to calculate a Present Year Net Benefit Value.

The calculation of EAD is the main difference between the Tornado BCA methods and other methods for other hazard or project types. The main governing equation for both EAD(Before) and EAD(After) is:

$$EAD(Before) = \sum_{EF=0}^{5} EAD(EF, Before) \qquad (5)$$

Where:

EAD (EF, Before) = Expected Annual Damages before mitigation for each of the 5 Enhanced Fujita (EF) Classes, based on injuries and deaths (in dollars).

$$EAD(EF, Before) = \sum_{Injury=1}^{4} EAD(Injury, EF, Before) \qquad (6)$$

Where:

EAD (Injury, EF, Before) = Expected Annual Damages before mitigation for each Enhanced Fujita Class for each injury severity level (in dollars).

$$EAD(Injury, EF, Before) = \sum_{Structure=1}^{N} EAD(Structure, Injury, EF, Before) \qquad (7)$$

Where:

N = Total number of before mitigation structures types (described in Section 5)

EAD (Structure,Injury, EF, Before) = Expected Annual Damages before mitigation for each Enhanced Fujita Class for each injury severity level for each before mitigation structure type (in dollars).

$$EAD(Structure,Injury,EF,Before) = (Prob.\ Tornado(EF) * Prob.\ Injury(Structure,Injury,EF,Before) * Cost(Injury) * Occupancy(Structure,Before)) \tag{8}$$

Where:

Prob. Tornado(EF) = Probability of the annual occurrence of a tornado for a particular EF Class (described in Section 4)

Prob. Injury(Structure, Injury, EF, Before) = Probability of injury for a particular injury class for a particular before mitigation structure type for a particular EF Class (defined in Section 5)

Cost(injury) = Cost associated with a particular injury class (described in Section 6)

Occupancy(Structure, Before) = Safe room occupancy for a particular before mitigation structure type (described in Section 7)

Section Three: Project Costs

3.1 Project Types and Design

The Tornado methodology allows for four different types of safe room project types, as follows:

- New Stand-alone Safe Room
- Retrofit Stand-alone Safe Room
- New Internal Safe Room
- Retrofit Internal Safe Room.

These project types apply to both residential safe rooms (as described in FEMA 320, *Taking Shelter From the Storm: Building a Safe Room Inside Your House*, March 2004 and later editions) and community safe rooms (as described in FEMA 361, July 2002 and later editions). The methodology assumes that safe room designs are compliant with the design and construction criteria presented in FEMA 320 and FEMA 361. **Safe room projects that are not compliant with FEMA 361 and/or FEMA 320 will be considered to have zero life-safety benefits.** Safe rooms that meet the FEMA 361 and/or FEMA 320 criteria are designed to provide near-absolute protection for safe room occupants.

3.2 Project Cost Estimation

The Cost Estimation Methodology is incorporated into the BCA software providing a common tool for all mitigation project types to develop costs estimates. The Cost Estimation methodology has been designed to apply estimating approaches that facilitate the development of accurate/complete cost estimates. It is not designed to replace an applicant's efforts to develop a scope of work, but to take an existing project scope and walk the applicant through the process of developing a cost estimate that includes all the typically anticipated steps for construction. This includes construction costs (such as materials, labor, and equipment) with additional project costs such as mobilization/demobilization, general contractor costs, owner costs, and escalation for project timing. The applicant is provided with helpful hints, sample work scope items, and a sample estimate associated with a typical stand alone safe room project from which to build project-specific cost estimate. For more information on the Cost Estimation Methodology please see the Cost Estimation Methodology Report.

Section Four: Probability of Tornado

4.1 Background

The Tornado Module development made use of the latest available National Oceanic and Atmospheric Administration (NOAA) tornado databases (1950-2006) to predict tornado occurrences throughout the US. Based on the latest research on tornado predictions and characteristics, the methodology used in the prior tornado BCA Module has been revised in several ways. One of the most important changes was accounting for the new research in revising the Fujita Scale.

4.2 Enhanced Fujita Scale

The Fujita Scale, a method correlating wind speeds with damages from tornadoes, has been used for over 30 years. In recent years, however, it has become more apparent that the Fujita Scale has many limitations. For instance, this method has very few damage indicators, does not account for construction quality, and has no definitive correlation between damages and wind speeds.

A group of tornado experts with experience dealing with Fujita Scale issues gathered to develop an improved method of measuring wind speeds associated with tornadoes, as detailed in Wind Science and Engineering Center (2006). The work from this expert group resulted in the Enhanced Fujita (EF) Scale. This scale includes 28 different damage indicators, corresponding to a wide range of structure types and infrastructure. For each damage indicator, the group developed detailed tables of degrees of damage (DOD), which provides detailed information about observable damages and corresponding wind speed ranges for that level of damage.

An important criterion for the resulting EF Scale was to be able to easily associate it with the Fujita Scale, so data collected in previous years would not be lost. This correlation was completed by using a regression analysis of the wind speeds from the Fujita and EF scales. The resulting scales contain the same six categories, from 0 to 5; however, the wind speeds have been adjusted in the EF scale for more accurate representation of the damages that occur within that category. Therefore, a tornado from the 1980s that was assigned a Fujita value of F2 would fall in the EF2 category today. Table 1 shows the correspondence between the Fujita Scale and the EF Scale. Table 2 shows the final wind speed ranges, where the breaks between different scales were rounded to the nearest 5 mph.

Table 1. EF-Scale Wind Speed Ranges Derived from Fujita-Scale Wind Speed Ranges (from Wind Science and Engineering Center, 2006)

Fujita Scale			**EF Scale**	
Fujita Scale	**Fastest ¼-mile Wind Speeds, mph**	**3-Second Gust Speed, mph**	**EF Scale**	**3-Second Gust Speed, mph**
F0	40-72	45-78	EF0	65-85
F1	73-112	79-117	EF1	86-109
F2	113-157	118-161	EF2	110-137
F3	158-207	162-209	EF3	138-167
F4	208-260	210-261	EF4	168-199
F5	261-318	262-317	EF5	200-234

Table 2. Final Recommended EF-Scale Wind Speed Ranges (from Wind Science and Engineering Center, 2006)

Derived EF Scale		**Final Recommended EF Scale**
EF Classes	**3-Second Gust Speed, mph**	**3-Second Gust Speed, mph**
EF0	65-85	65 – 85
EF1	86-109	86 – 110
EF2	110-137	111 – 135
EF3	138-167	136 – 165
EF4	168-199	166 – 200
EF5	200-234	>200

This correspondence between the Fujita class of existing tornado event records and the new EF classes allows the Tornado Module to use the EF scale as the basis for all tornado occurrence calculations. Therefore, the Module estimates tornado occurrence based on each of the 6 (EF 0 through EF 5) EF classes.

4.3 Tornado Location Calculations

The first step in determining tornado probability for the proposed location of a safe room for each EF class is an understanding of where tornadoes have occurred in the past. The tornado records, maintained by NOAA, store tornado location information in several different formats. For each tornado event, the database has fields for the location (latitude and longitude) of the tornado touchdown point, lift off point, and a separate listing of the counties that the path defined by these two points crosses. For many older events, some or all of these location fields may not be populated. The Expert Panel (described in Appendix A) recommended the use of the path and touchdown point as the most reliable and consistent location information available, which was then used for analysis.

The next tornado location issue to address was the need to aggregate this point and line data to produce probability estimates over a wide area. While the module may lookup probability information on a county-basis, the irregular size and location of counties introduces statistical issues. Commonly called the "Modifiable areal unit problem", the arbitrary shape and location of units (in this case counties) may not allow regional analysis to fully show the actual spatial trends in data. Small counties may contain little or no events, while a neighboring large county may have a large number of events. This results in having a zero or low probability county next to a high probability county. This does not agree with expert experience of tornado occurrence being regional with very gradual changes in likelihood over large areas.

Therefore, the panel suggested using the analysis area or "cell" based approach as detailed in Ashley (2007). In this research, 60 km by 60 km equal area cells were used throughout the continental US. to count tornado occurrences from touchdown data. In addition, a low pass 3 X 3 filter was also applied to these counts to smooth regional contour maps developed to show the trends of tornado occurrence. The filtering and smoothing also helped make the regional estimate more consistent and made up for lack of recorded events in low population areas.

The approach outlined in Ashley (2007) was used for the Tornado Module, with one modification to the cell area. Brooks et. al. (2003) conducted analysis based on raster cells with 80-km spacing vertically and horizontally, which roughly corresponds to the area used for Storm Prediction Center forecasts. The Expert Panel agreed that the 80-km cells provide a better basis for analysis.

Appendix B contains a listing of the analysis steps used to produce the final tornado occurrence contour maps for each EF class. Appendix C shows all the maps for each EF class through the three main steps of the analysis (EF 0 maps shown below): Step 1. Raw tornado counts in each cell, Step 2. Low pass filter results, Step 3. Smoothed Contours.

Figure 1. Raw tornado counts for EF 0 (1950-2006)

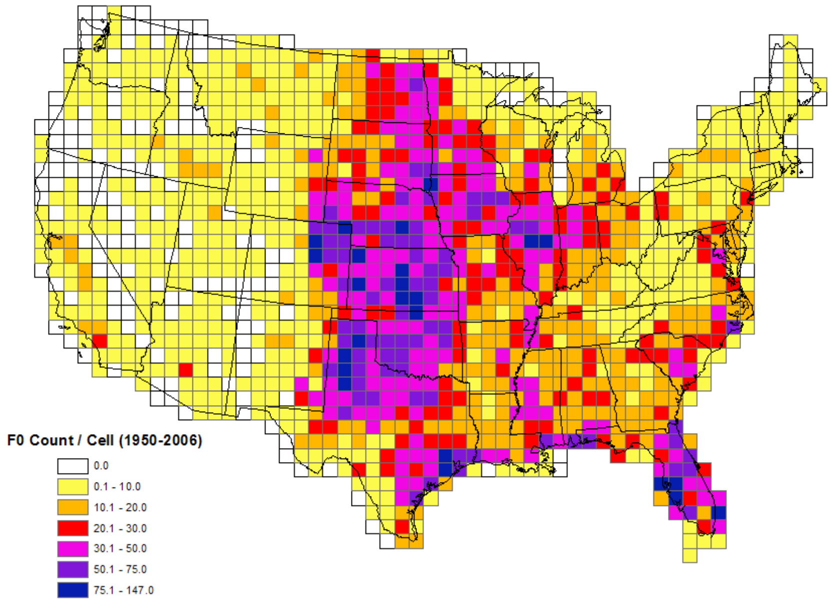


Figure 2. Low pass filter results for EF 0 (1950-2006)

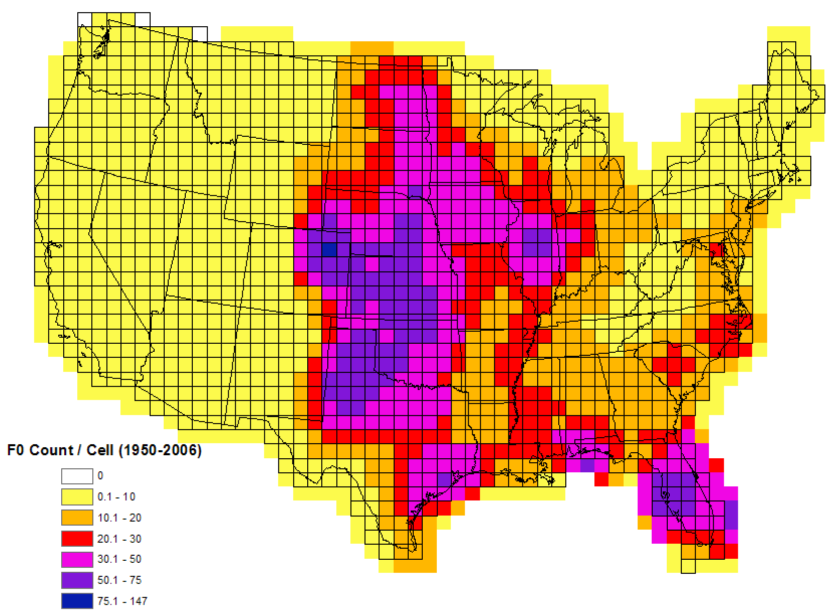
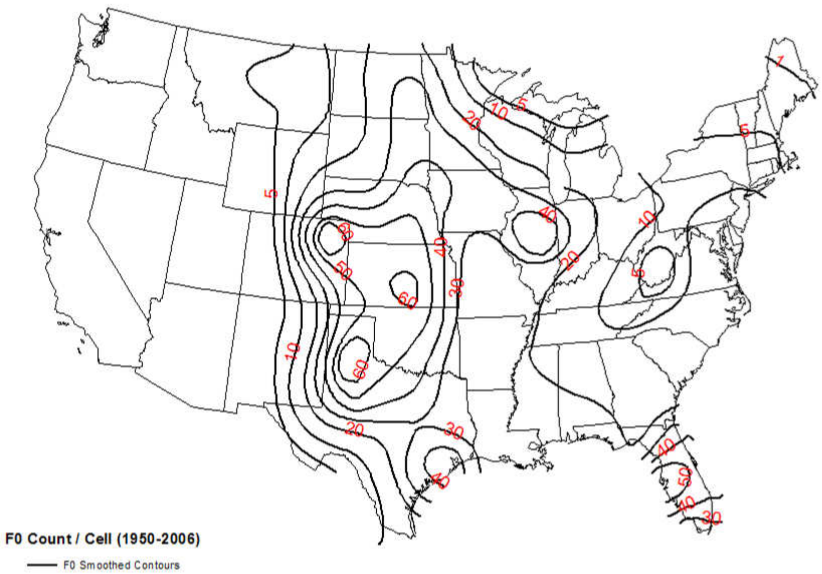


Figure 3. Smoothed contour results for EF 0 (1950-2006)



With these contour maps developed, the final step is to use a GIS-based approach to extract a value (predicted tornado count for the time period 1950-2006) for each county for each EF class. Table 3 below shows an example count extracted for a specific county.

Table 3. Example of Tornado Counts by EF class from contour mapping.

EF Classes	Counts
EF0	12
EF1	22
EF2	15
EF3	7
EF4	2
EF5	0.5

4.4 Tornado Area Calculations

The NOAA tornado event database contains information with a tornado's path length and width, stored not with a specific value, but in number of categories that represent a range of values. The Expert Panel commented tornado size information is much less reliable than data like EF class or location. Averages or general trends should be used in place of event-specific data to determine tornado area of impact.

Therefore, an average width and length was used for each EF class. Brooks (2004) developed national means for tornado length and width for each EF-class, as listed in Table 4.

Table 4. Mean Tornado Length and Width by EF Class (from Brooks, 2004).

EF Classes	Length (km)	Width (m)
EF0	1.4	28.4
EF1	4.7	64.0
EF2	10.7	125.9
EF3	22.5	263.6
EF4	43.6	460.7
EF5	54.6	555.5

4.5 Tornado Probability Calculations

The final step in calculating the tornado probability to use in Equation 8 is to combine the tornado counts and tornado area data in the following equation:

$$\textit{Prob. Tornado(EF)} = (\textit{EF count} * \textit{EF area}) / (\textit{Cell area} * \textit{Years}) \qquad (9)$$

Where:

EF count = Estimate tornado count for EF class from mapping (for example, from Table 3)

EF area = Area of tornado for EF class based on Table 4 (km^2)

Cell area = Area of analysis cell, 80 km * 80 km or 6400 km^2

Years = Years of record from 1950 to 2006 or 57 years

Table 5 shows the results of this equation when applied to Table 3

Table 5. Example Tornado Probability by EF class based on Table 3.

EF Classes	**Probability**
EF0	$1.3 * 10^{-06}$
EF1	$1.8 * 10^{-05}$
EF2	$5.5 * 10^{-05}$
EF3	$1.1 * 10^{-04}$
EF4	$1.1 * 10^{-04}$
EF5	$4.2 * 10^{-05}$

Section Five: Probability of Injury and Death

5.1 Background

The main task of the Expert Panel was to produce updated versions of the injury and death tables that show how different wind speeds impact the occupants in different structure types. The three main components of these tables are the following:

- Structure Types
- Structure Damage Classes
- Injury Classes

5.2 Structure Types

The EF report (Wind Science and Engineering Center, 2006) provided details about the degree of damage (DOD) for different structure types over a range of wind speeds. The expert panel wanted to utilize this information to aid in the development of the new injury and death tables. Therefore, the panel developed a list of structure types that represented a range of structures where occupants would reside either before a safe room is built or type of safe room. Table 6 contains the final list of structure types from the expert panel.

Table 6. Structure Types in the Tornado Module, based on Wind Science and Engineering Center, 2006

Structure Types	Description
Single Family Residence	Pre-safe room structure type, based on FR12 damage indictor category from EF Report
Manufactured Home	Pre-safe room structure type, based on MHDW damage indictor category from EF Report
Metal Building	Pre-safe room structure type, based on MBS damage indictor category from EF Report
Small Professional Building	Pre-safe room structure type, based on SPB damage indictor category from EF Report
Schools (K-12)	Pre-safe room structure type, based on JHSH damage indictor category from EF Report
Institutional Building	Pre-safe room structure type, based on IS damage indictor category from EF Report
Open	Pre-safe room structure type, not based on EF Report, represents worse case scenario
Safe Room 130 MPH Design	Safe room structure type, based on FEMA 361 Report
Safe Room 160 MPH Design	Safe room structure type, based on FEMA 361 Report
Safe Room 200 MPH Design	Safe room structure type, based on FEMA 361 Report
Safe Room 250 MPH Design	Safe room structure type, based on FEMA 361 Report

5.3 Structure Damage Classes

The next challenge in developing the injury and death tables was to relate the DOD tables from the EF report into common structure damage classes. Appendix E shows the DOD tables for different structure types, such as the Single Family Residential (FR12) table show in Table 7.

Table 7. Single Family Residential (FR12) Degree of Damage Table from EF Report (Wind Science and Engineering Center, 2006)

Degree of Damage (DOD)	Damage Description	Expected Wind Speed Value (mph)
1	Threshold of visible damage	65
2	Loss of roof covering material (<20%), gutters and/or awning; loss of vinyl or metal siding	79
3	Broken glass in doors and windows	96
4	Uplift of roof deck and loss of significant roof covering material (>20%); collapse of chimney; garage doors collapse inward; failure of porch or carport	97
5	Entire house shifts off foundation	121
6	Large sections of roof structure removed; most walls remain standing	122
7	Exterior walls collapsed	132
8	Most walls collapsed, except small interior rooms	152
9	All walls collapsed	170
10	Destruction of engineered and/or well constructed residence; slab swept clean	200

Each structure type with a corresponding DOD table has a different damage description. Therefore, the expert panel decided to develop common structure damage classes to aid in the development of the injury and death tables. Table 8 lists the structure damage classes.

Table 8. Structure Damage Classes used in the Tornado Module

Structure Damages Classes	Description
No Damage or very little	
Minor Damage	Includes broken windows and trees falling on structures
Moderate Damage	Portions of external walls beginning to fail, some internal damage
Severe Damage/Partial Collapse	Several internal or external walls collapsed
Total Collapse	All internal and external walls collapsed
Complete Destruction	Clean slab

Table 9 shows how these structure damage classes relate to the DOD's of those structure types from the EF report.

Table 9. Relation between Structure Damage Classes and EF Report DOD's (Wind Science and Engineering Center, 2006)

Structure Types	No damage or very minor	Minor damage	Moderate damage	Severe damage/partial collapse	Total collapse	Complete destruction
Single family	1,2	3,4	5,6	7	8,9	10
Manufactured Housing	1,2	3	4	5	6	7,8,9
Metal Bldg	1	2	3	4,5,6	7	8
Small Professional Bldg	1,2	3	4,5,6	7	8	9
Elementary School	1,2	3,4	5,6	7,8	9	10
Jr./Sr. High School	1,2	3,4	5,6	7,8,9	10	11
Inst. Bldg	1,2	3,4	5,6	7,8,9	10	11

5.4 Injury Classes

The Expert Panel established the injury classes based on available data from Federal Aviation Administration (FAA), specifically "Economic Values for FAA Values in Regulatory and Investment Decisions, A Guide" 2004. The FAA injury table, shown in Table 10, contains the 6 Abbreviated Injury Severity (AIS) Codes), injury severity levels, and associated injuries.

Table 10. FAA Injury Level Categories (FAA 2004)

Abbreviated Injury Severity (AIS) Code	Injury Severity Level	Selected Injuries
1	Minor	Superficial abrasion or laceration of skin; digit sprain; first-degree burn; head trauma with headache or dizziness (no other neurological signs)
2	Moderate	Major abrasion or laceration of skin; cerebral concussion (unconscious less than 15 minutes); finger or toe crush/amputation; closed pelvic fracture with or without dislocation
3	Serious	Major nerve laceration; multiple rib fracture (but without flail chest); abdominal organ contusion; hand, foot, or arm crush/ amputation
4	Severe	Spleen rupture; leg crush; chest-wall perforation; cerebral concussion with other neurological signs (unconscious less than 24 hours)
5	Critical	Spinal cord injury (with cord transaction); extensive second- or third-degree burns; cerebral concussion with severe neurological signs (unconscious more than 24 hours)
6	Fatal	Injuries which although not fatal within the first 30 days after an accident, ultimately result in death

Based on the expert panel's experience in post-disaster research, the gathering of information about injuries in these six categories is very difficult. The panel reduced the number of categories to 4, as shown in Table 11. Also shown in Table 11 are the corresponding AIS codes.

Table 11. Injury Classes used in the Tornado Module (Based on FAA values).

Injury Classes	FAA AIS Code
Death	5,6
Hospitalized	3,4,5
Treat & release	1, 2
Self treat	1

5.5 Injury and Death Tables

For each structure type listed in Table 6, the expert panel developed injury and death tables to estimate the percentage of a structure's occupants in different injury classes, listed in Appendix E. Table 12 shows an example of the table for single family residential.

Table 12. Example injury and death table for Single Family Residential Structure Type.

	% Self treat	% Treat & release	% Hospitalized	% Fatal
No event	0	0	0	0
No damage or very minor	5	5	0	0
Minor damage	20	20	5	0
Moderate damage	20	20	10	0
Severe damage/partial collapse	30	20	10	5
Total collapse	30	30	20	10
Complete destruction	10	10	30	50

These tables were developed based on expert opinion and a review of historical tornado events to similar structure types. The reference section of this document lists some of the references to these historical events.

The tables for the structure types based on the EF report were developed based on a similar format to Table 12. The injury and death tables for the Open structure type and the four Safe Room structure types used the same injury classes, but used wind speed ranges instead of structure damage classes. See Appendix D for a more detailed description of the basis for these tables.

5.6 Probability of Injury and Death Calculations

Equation 8 requires a value for the probability of injury (or death) based on structure type (including the before or after safe room scenario), injury class, and EF class. Therefore all the injury and death tables developed by the expert panel were converted to tables giving the injury class by EF class. Appendix D gives a detailed account of this calculation. Table 13 shows an example of one of these calculations for the hospitalization injury class for the single family residential structure type. Appendix E gives similar tables for all structure types. These tables are used directly in the Tornado Module for the Probability Injury (Structure, Injury, EF Before) factor in Equation 8.

Table 13. Calculated hospitalized values for single family residential

EF Classes	**Wind Speeds (mph)**	**% Hospitalized**
	0 - 64	0
EF0	65 - 85	0
EF1	86 - 110	5
EF2	111 - 135	10
EF3	136 - 165	15
EF4	166 - 200	24
EF5	>200	30

Section Six: Injury and Fatality Costs

6.1 Background

As mentioned in Section 5, the Expert Panel used a modified version of the FAA Injury Severity Levels. Each of the FAA levels has an associated cost that can be used to assign a dollar amount to each injury class used in Tornado Module. Table 14 below lists the "willingness to pay" (WTP) value and the fraction associated with each injury severity level. The table listed the value in 2001 value and the current 2008 .

Table 14. WTP Descriptors and Values (FAA, 2008)

AIS Code	Description of Injury	Fraction of WTP Value of Life	WTP Value (2001)	WTP Value (2008)
AIS 1	Minor	0.20%	$ 6,000.00	$ 12,000.00
AIS 2	Moderate	1.55%	$ 46,500.00	$ 90,000.00
AIS 3	Serious	5.75%	$ 172,500.00	$ 334,000.00
AIS 4	Severe	18.75%	$ 562,500.00	$ 1,088,000.00
AIS 5	Critical	76.25%	$ 2,287,500.00	$ 4,423,000.00
AIS 6	Fatal	100%	$ 3,000,000.00	$ 5,800,000.00

6.2 Methods

Table 14 can be used to develop the cost for injury and death to match up with the injury classes used in the Tornado Module. Table 15 lists each of the injury classes and the rounded values based on Table 14. These values are used directly in Equation 8.

Table 15: Cost of Injury and Death Values used in the Tornado Module.

Injury Severe Levels	AIS Cats	Fraction of WTP Value of Life	$ WTP Value (rounded)
Fatal	5,6	100.00%	$ 5,800,000
Hospitalized	3,4,5	18.75%	$ 1,088,000
Treat & release	1, 2	1.55%	$ 90,000
Self treat	1	0.20%	$ 12,000

Section Seven: Occupancy

7.1 Background

The final factor needed to determine the benefits from a safe room is the occupancy. The Tornado Module allows up to two different before-mitigation structure types and one after-mitigation (safe room) structure type. All the occupants of the safe room are assumed to be in the pre-safe room structure types before the safe room is constructed. The factors that impact occupancy are as following:

- Time of Day
- Pre-Safe Room Occupancy Percentage
- Tornado Warning Response

Starting with a maximum safe room occupancy, these three factors work together to influence the occupant levels used in the Tornado Module. The Module user will need to develop the maximum occupancy estimate as part of their project development process.

7.2 Time of Day

Occupancy is split into three times of day as shown in Table 16. This division was conducted by the expert panel in an effort to better approximate the number of people at the safe room for different times of day.

Table 16. Occupancy Time of Day used in the Tornado Module

	Time (military time)	
	Start	**End**
Day	600	1800
Evening	1800	2400
Night	0	600

7.3 Pre-Safe Room Occupancy Percentage

The Tornado Module allows up to two pre-safe room structure types. For each of these structure types for each time of day, the user needs to enter the percent of the maximum occupancy that would have been in the structure for the pre-safe room scenario. Table 17 shows an example where most of the safe room occupants would have been in structure type 2 during the day, an even split during the evening, and all occupants would have been in structure type 1 at night.

Table 17. Example Pre-Safe Room Occupancy Ratio Table (1.0 = 100%)

	Structure Type 1	**Structure Type 2**
Day	0.1	0.9
Evening	0.5	0.5
Night	1.0	0.0

7.4 Tornado Response Percentage

The expert panel requested the module also include a tornado warning response factor. Past research, such as Paul *et. al.* (2003), has shown that even in "tornado alley" only a percentage of people who receive a tornado warning will travel to a safe room. This is especially true during the night. Based on Paul *et. al.* (2003) and the expert panel, Table 18 lists the default response percentage given in the Tornado Module. A user can override these values for either or both before-mitigation structure types with local values when available.

Table 18. Default Tornado Response Ratios used on Tornado Module (1.0 = 100%)

	Response Percentage
Day	1.00
Evening	0.85
Night	0.60

7.5 Total Occupancy Calculation

Equation 8 requires *Occupancy(Structure,Before)*. The occupancy for each of the pre-safe room structure types needs to be calculated separately, since each structure type will have a different injury and death table.

$$Occupancy(Structure, Before) =$$

$$Max.Occupancy * \sum_{Time=Day}^{Night} Occ.Percentage(Structure, Time) * Response(Structure, Time)$$

$$(10)$$

Where:

Max.Occupancy = Maximum Safe Room Occupancy, must have at least 5 ft^2 per occupant for safe room area.

Time = Time of Day (Day, Evening, Night).

Occ.Percentage (Structure,Time) = Occupancy percentage by pre-safe structure type and by time of day.

Response (Structure,Time) = Tornado response percentage by pre-safe structure type and by time of day.

In addition, the after safe room scenario will require the sum of the two pre-safe room occupancies.

$$Occupancy(Structure, After) = \sum_{StructureType=1}^{2} Occupancy(Structure, Before) \qquad (11)$$

Where:

StructureType = Pre-safe room structure types.

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Appendix A: Expert Panel

The Tornado Expert Panel was made up of the following experts on tornado and injuries and deaths from hazards:

Dr. Walker Ashley	Meteorologist, Assistant Professor, Meteorology Program, Department of Geography, Northern Illinois University
Thomas Smith, AIA, RRC, CSI	Architect, TLSmith Consulting Inc., assisted with Enhanced Fujita development
Dr. Tim Reinhold	Engineer, Director of Engineering & Vice President, Institute for Business & Home Safety, assisted with Enhanced Fujita development
Hope Seligson	Earthquake and Life Safety Expert, Associate, MMI Engineering, Inc.
Dr. Kimberley Shoaf	Public Health Expert, Associate Professor In Residence in the Department of Community Health Sciences in the UCLA School of Public Health, Assistant Director of the UCLA Center for Public Health and Disasters, University of California, Los Angeles
E. Scott Tezak, PE, BSCP	Safe Room and Shelter Building Science Expert, URS Corporation.

The panel was used in two different ways in development of the Tornado Module. First, the entire panel met on November 15 and 16, 2007, to develop the injury and death tables as detailed in Section 5. Based on feedback from the panel on other parts of the methodology, panel members with tornado modeling experience (Ashley, Smith, Reinhold, Tezak) were also used to evaluate and refine the overall Tornado Module methodology.

Appendix B: Tornado Probability Map Methods

The tornado probability maps used to estimate annual probability for EF0 through EF5 tornadoes were developed using GIS software (ESRI ArcGIS 9.1). The following steps describe the procedure used to go from the original source data to the final county-based lookup tables.

1. Download 1950-2006 NOAA tornado path and touchdown point data from http://204.227.127.209/ind/?n=svrgis. This data represented a compilation of the NOAA event-based tornado database into GIS (ESRI shapefile) format.

2. Create new GIS project using an equal area projection. The North America Albers Equal Area Conic was used for the mapping.

3. Import tornado GIS data into GIS project.

4. Create a polygon-based grid to cover the entire extent of the lower 48 US states and all the tornado data. Grid extent based on equal area projection major grid coordinates, 80 km X 80 km.

5. Count number of tornados in each EF-class as follows:

    a. From touchdown data points, remove those points that have a path available. Save these points with no paths as a separate file.

    b. Count touchdown points with no path for each EF-class with the polygon grid.

    c. Count paths for each EF-class for each grid. Paths are clipped to each grid and then counted.

    d. Add up point and path counts for total tornado counts per EF-class for each grid.

7. Convert polygon grid to raster grid.

8. Apply low pass 3X3 filter. This is the same as applying a mean filter for 3X3 cells.

9. Convert grid to points at the center of the girds.

10. Apply IDW interpolation to points. Parameters used 4000 km size, Power 1, 12 points, variable radius.

11. Create contours for each EF-class (see final maps in Appendix C for contour intervals).

12. Clip contours to the USA.

13. Select certain contours that show major trends.

14. Smooth contour line. Parameters used: Paek method, 400 km.

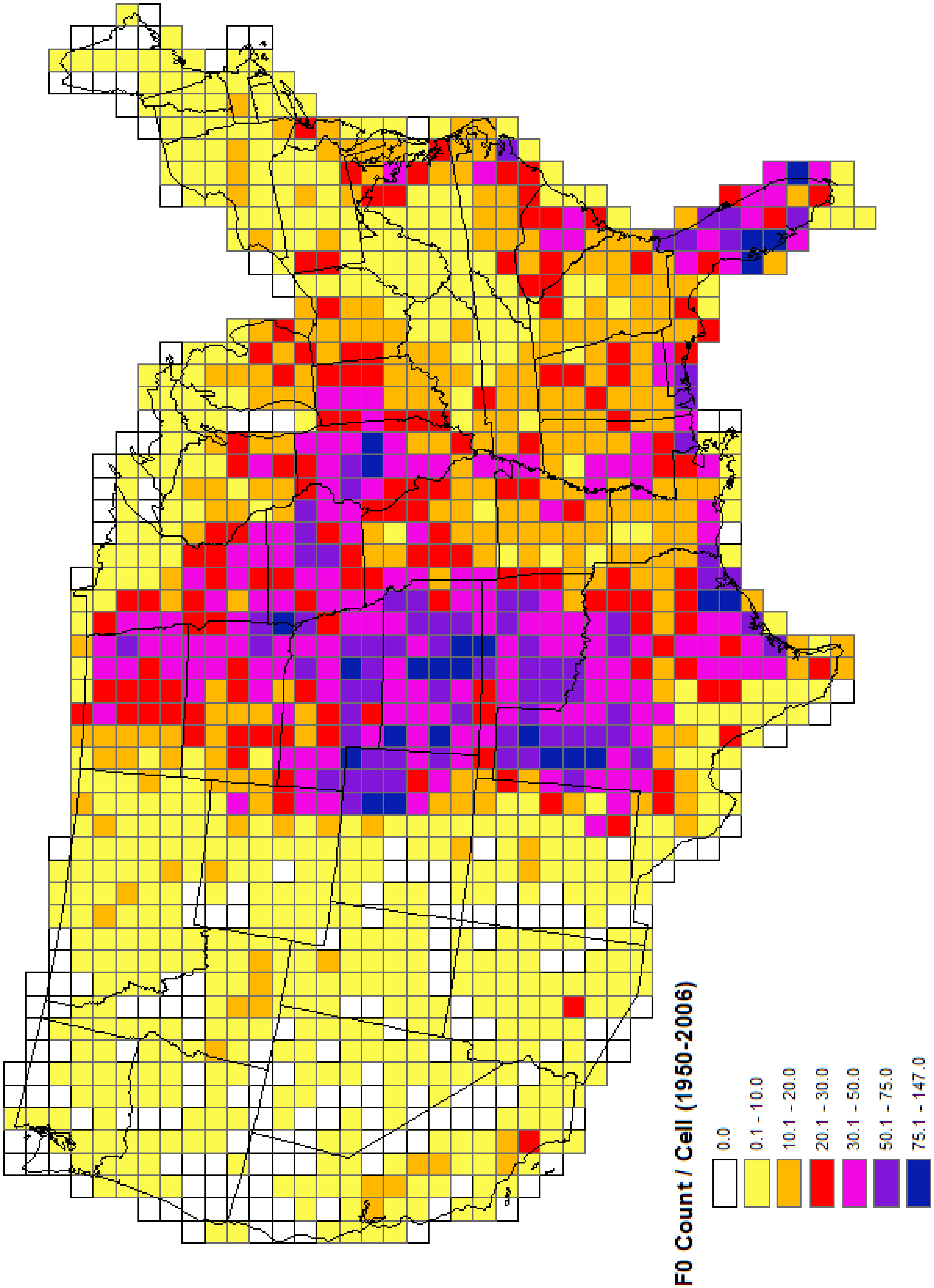
15. Edit smoothed lines. Delete all data artifacts (small contours). Selectively delete “donuts” or features that show extreme local variation.

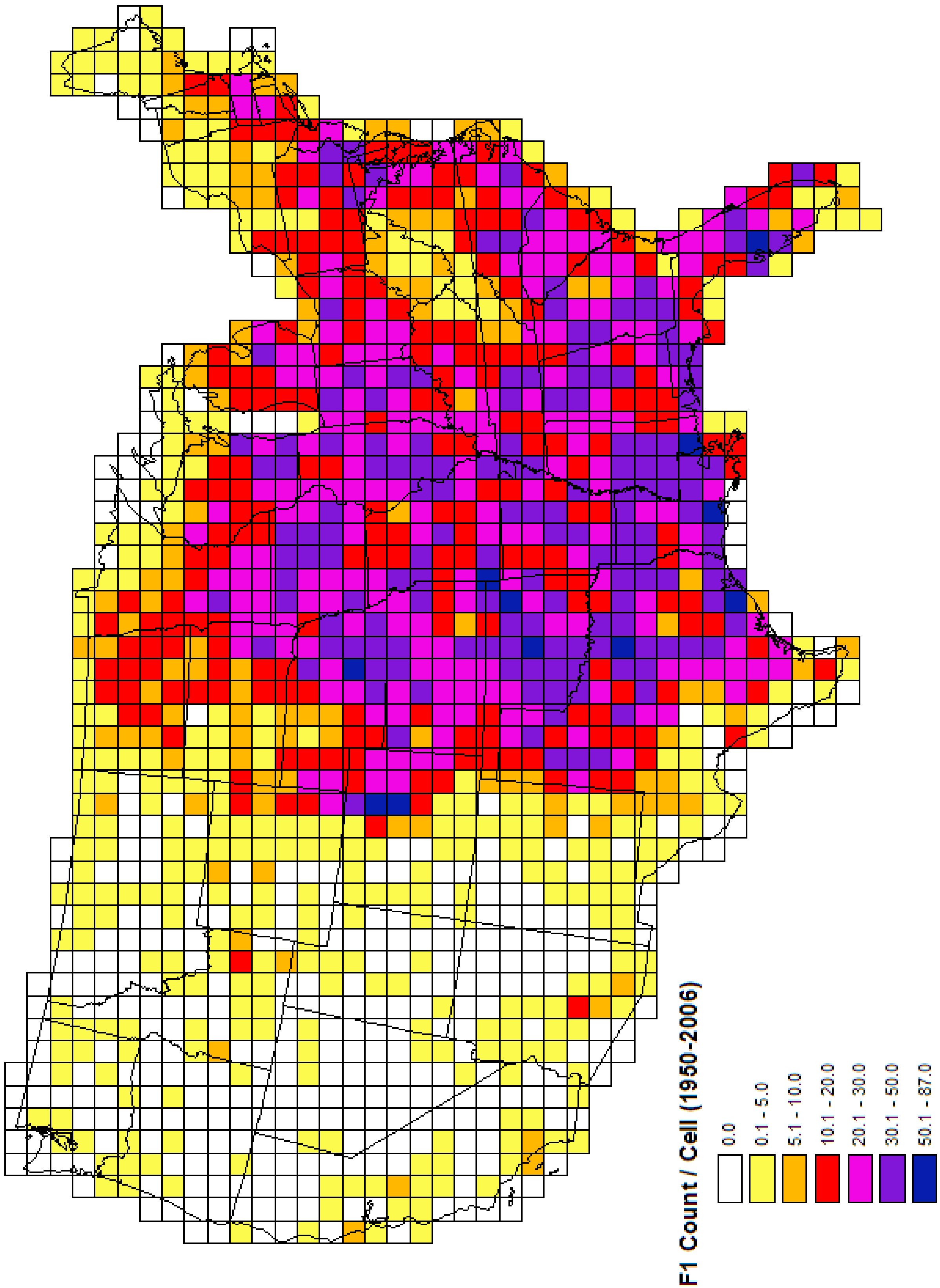
16. Use contour lines to define surface (TIN).

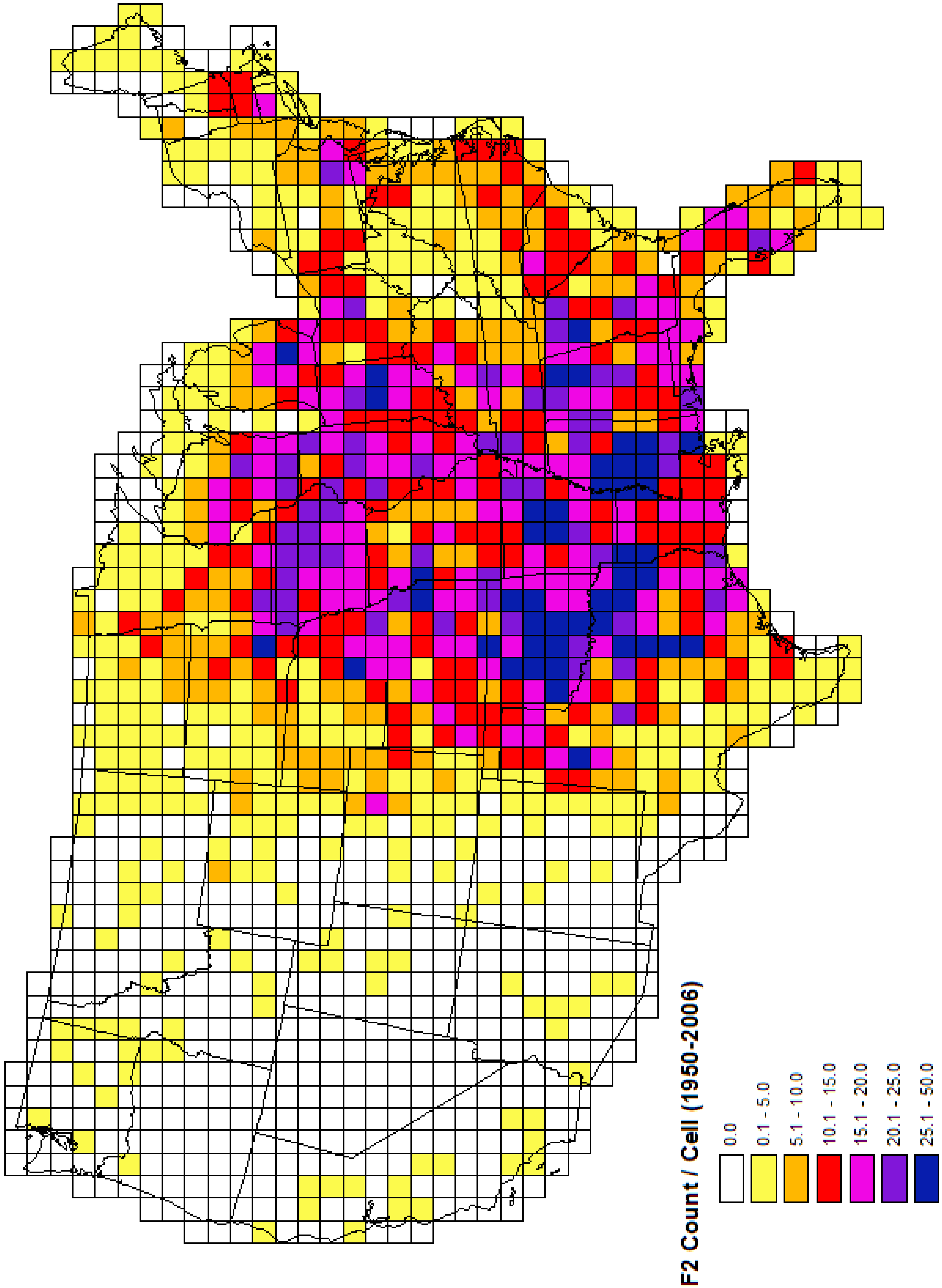
17. Interpolate counts for each EF-class for each county from surface using area weighted averaging.

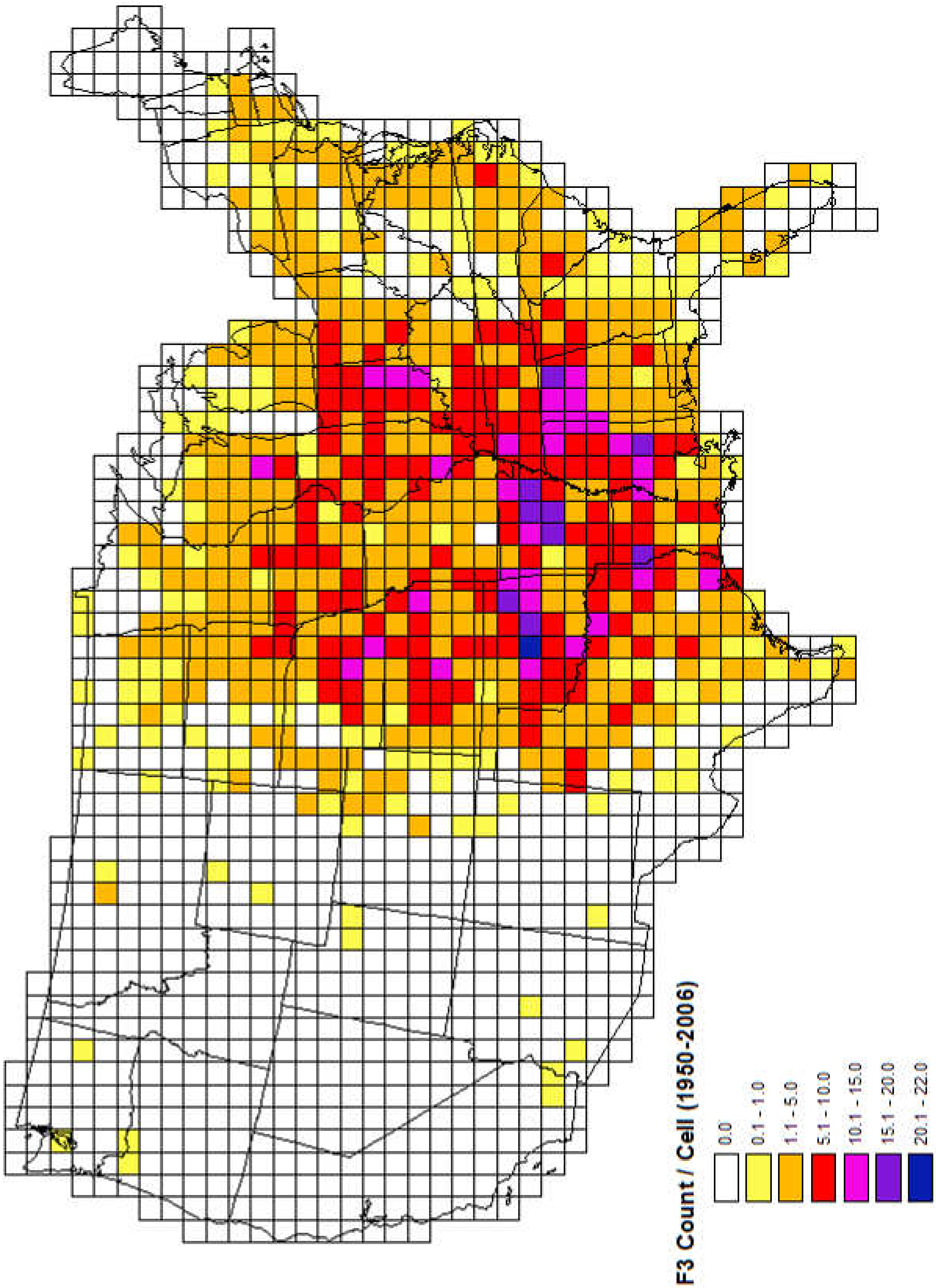
Appendix C: Tornado Probability Mapping

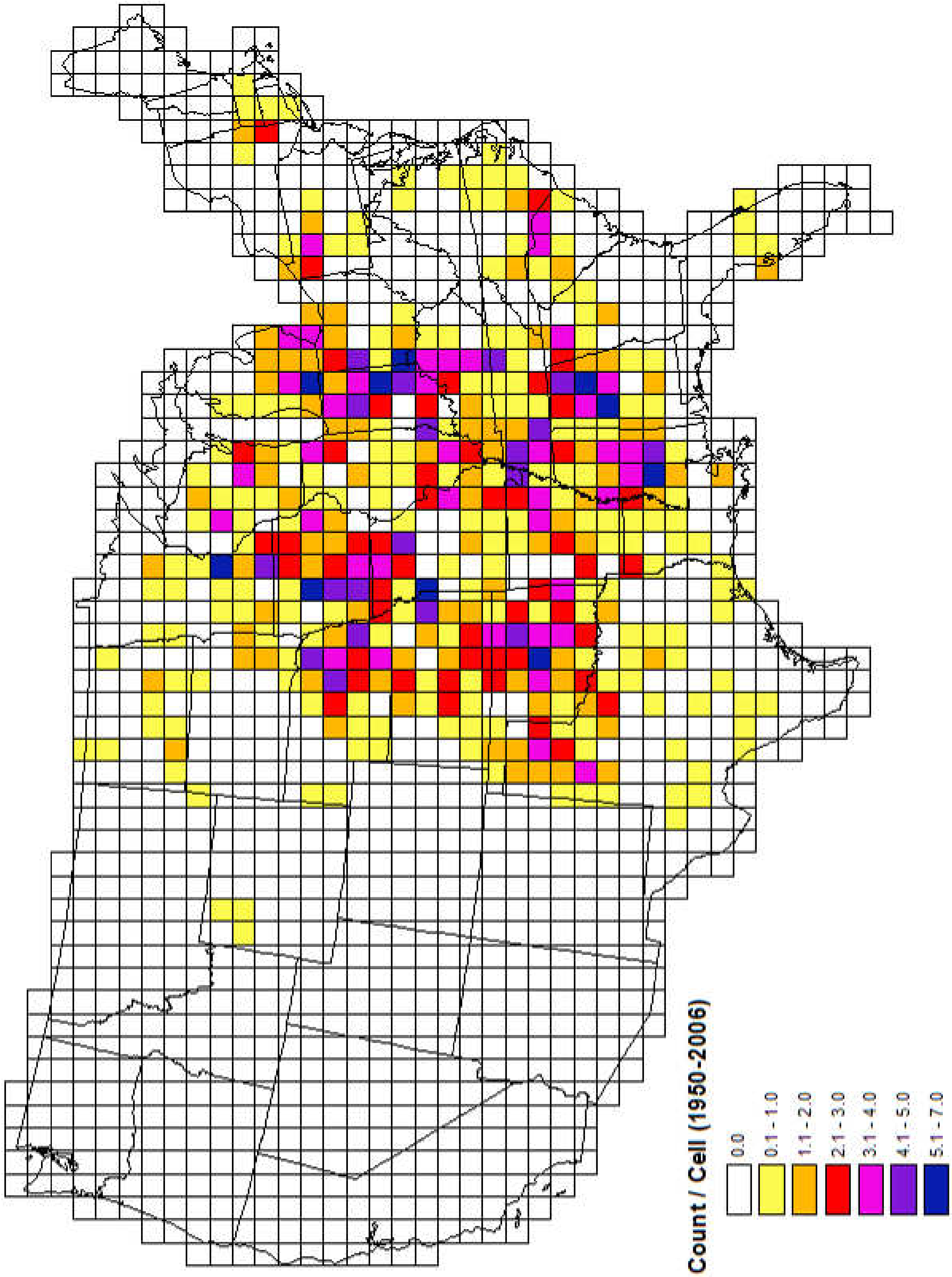
Step 1: Raw Tornado Counts per cell per EF-class

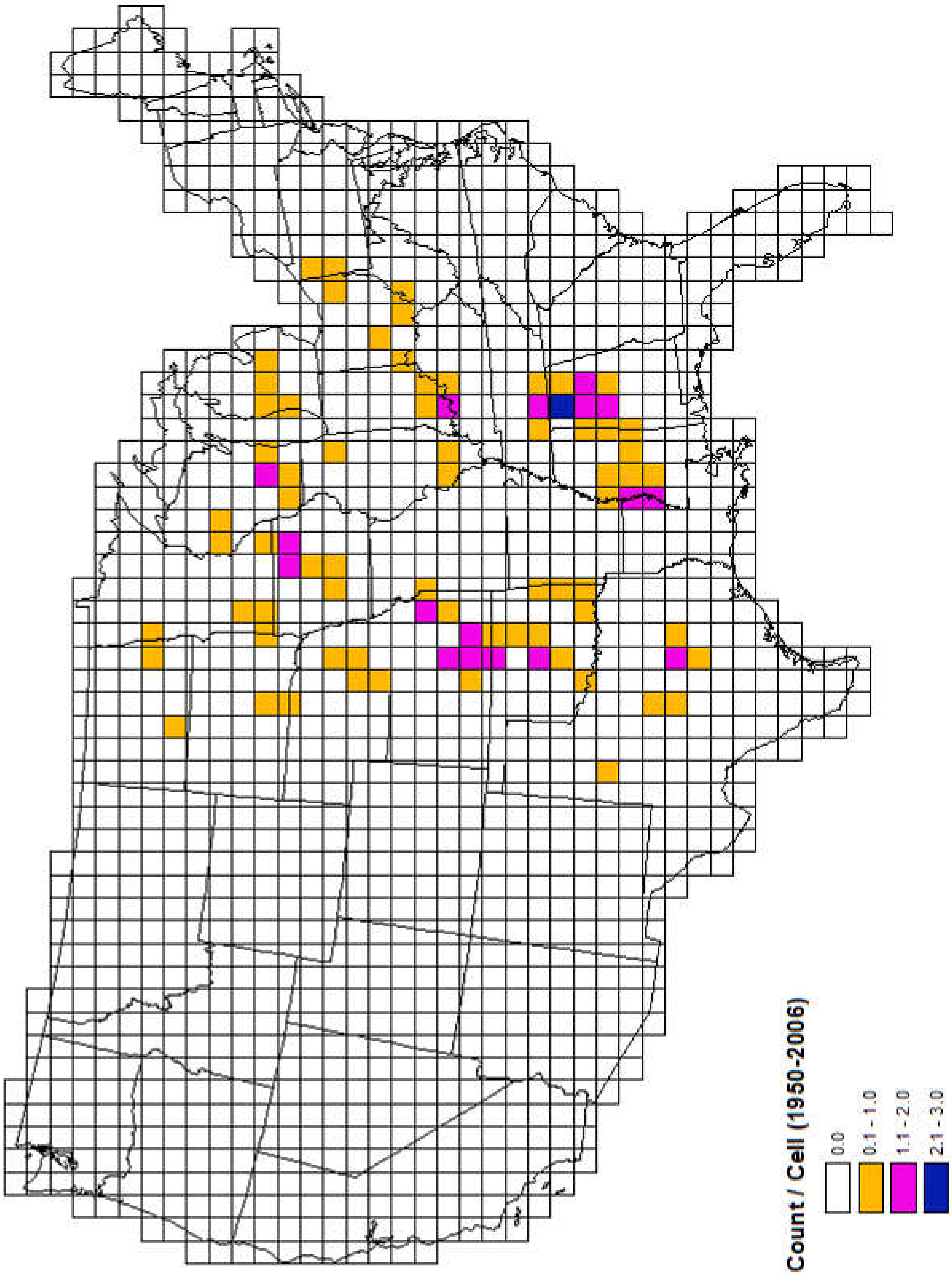

F0 Count / Cell (1950-2006)
0.0
0.1 - 10.0
10.1 - 20.0
20.1 - 30.0
30.1 - 50.0
50.1 - 75.0
75.1 - 147.0


F1 Count / Cell (1950-2006)
0.0
0.1 - 5.0
5.1 - 10.0
10.1 - 20.0
20.1 - 30.0
30.1 - 50.0
50.1 - 87.0

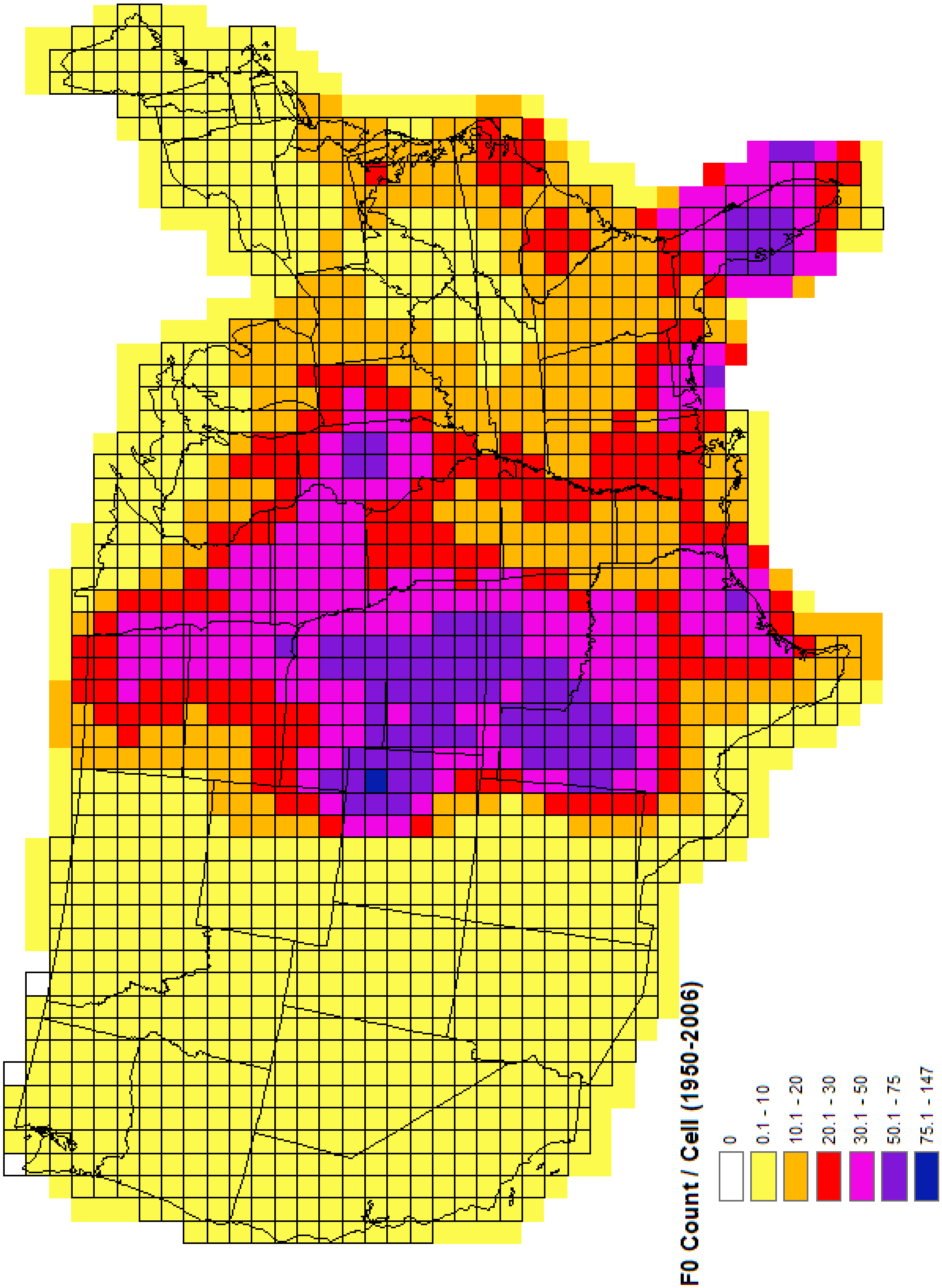

F2 Count / Cell (1950-2006)
0.0
0.1 - 5.0
5.1 - 10.0
10.1 - 15.0
15.1 - 20.0
20.1 - 25.0
25.1 - 50.0

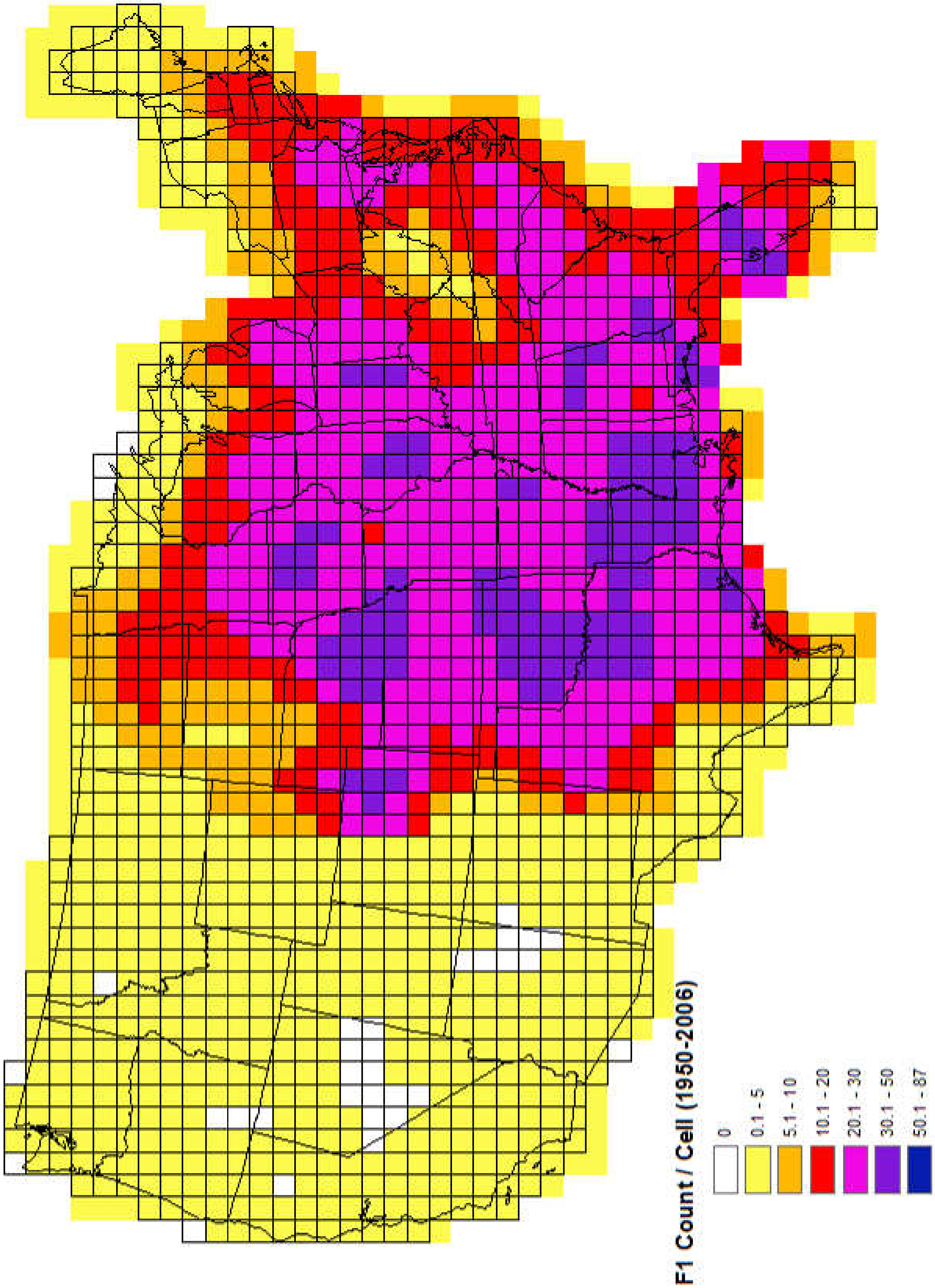

F3 Count / Cell (1950-2006)
0.0
0.1 - 1.0
1.1 - 5.0
5.1 - 10.0
10.1 - 15.0
15.1 - 20.0
20.1 - 22.0

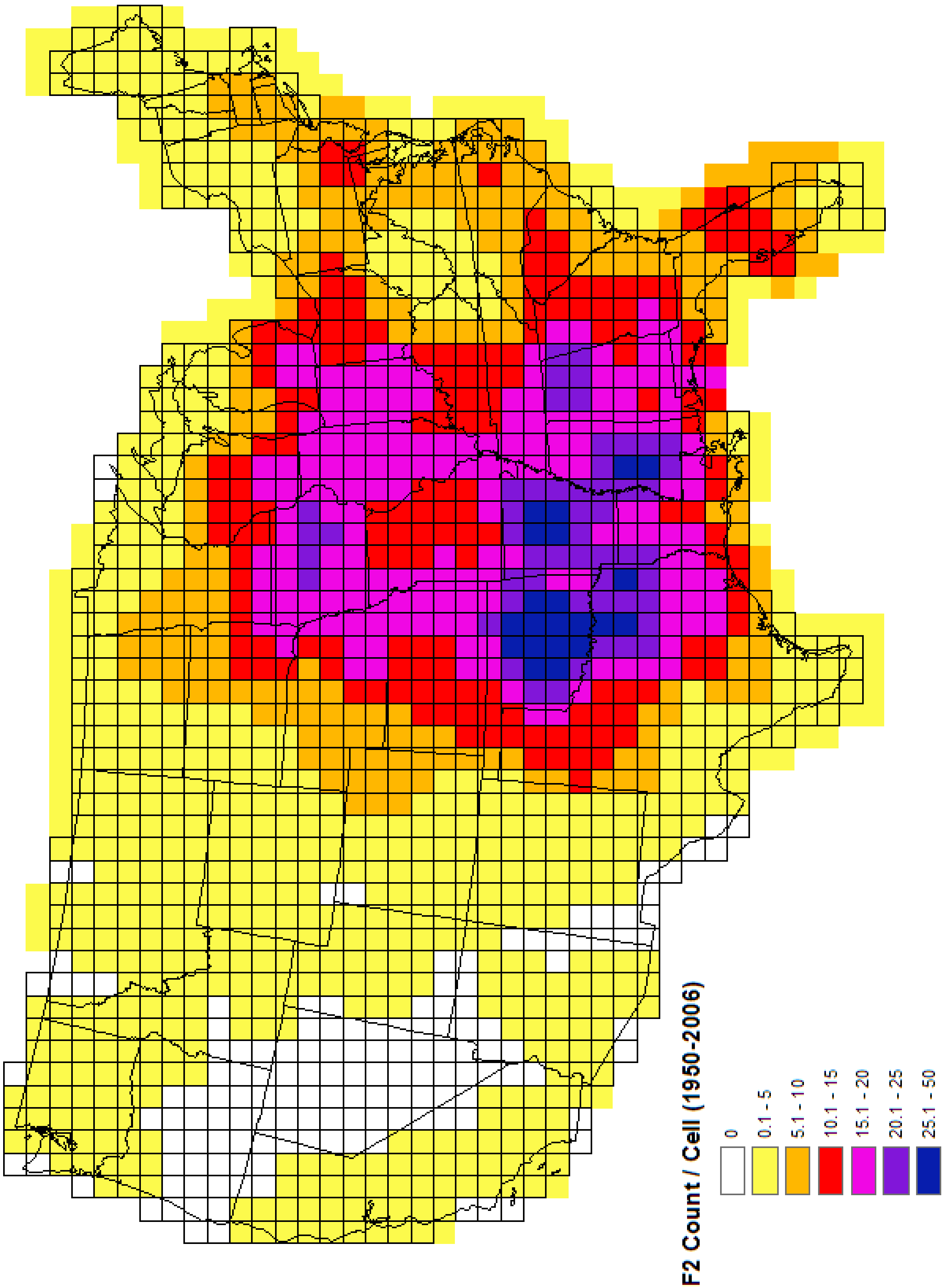

F4 Count / Cell (1950-2006)
0.0
0.1 - 1.0
1.1 - 2.0
2.1 - 3.0
3.1 - 4.0
4.1 - 5.0
5.1 - 7.0


F5 Count / Cell (1950-2006)
0.0
0.1 - 1.0
1.1 - 2.0
2.1 - 3.0

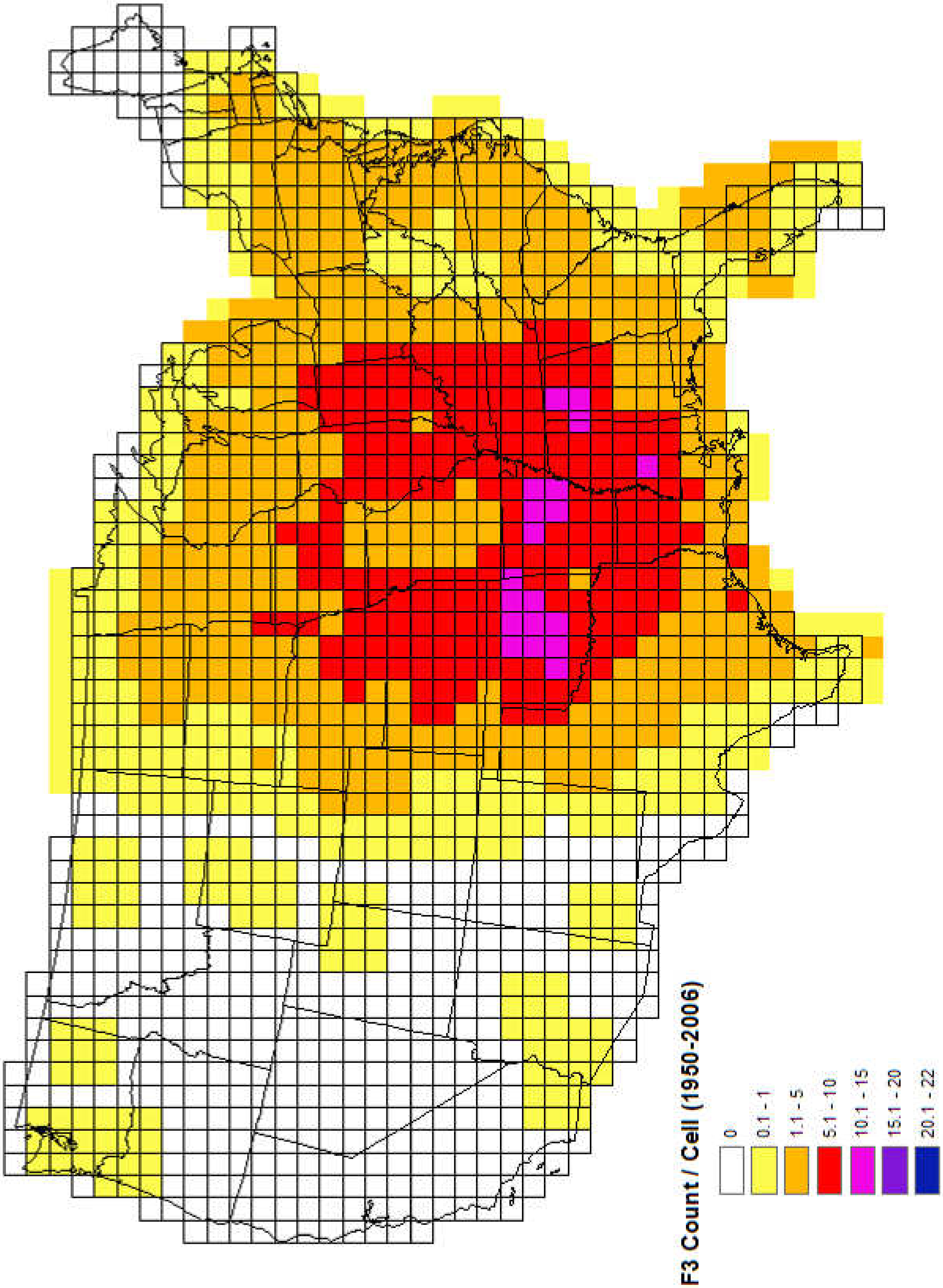
Step 2: Smoothed Tornado Counts per cell per EF-class

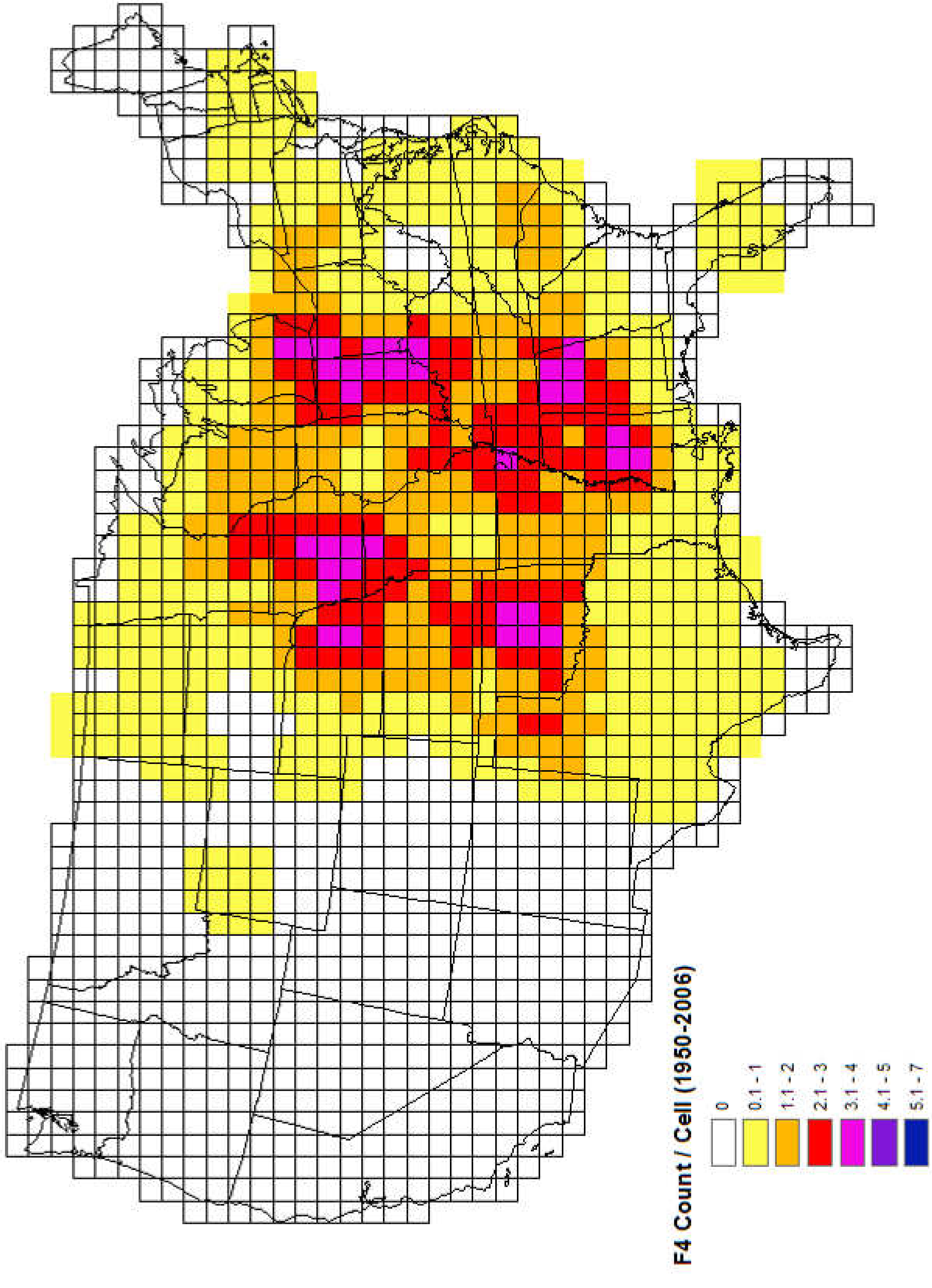

F0 Count / Cell (1950-2006)
0
0.1 - 10
10.1 - 20
20.1 - 30
30.1 - 50
50.1 - 75
75.1 - 147

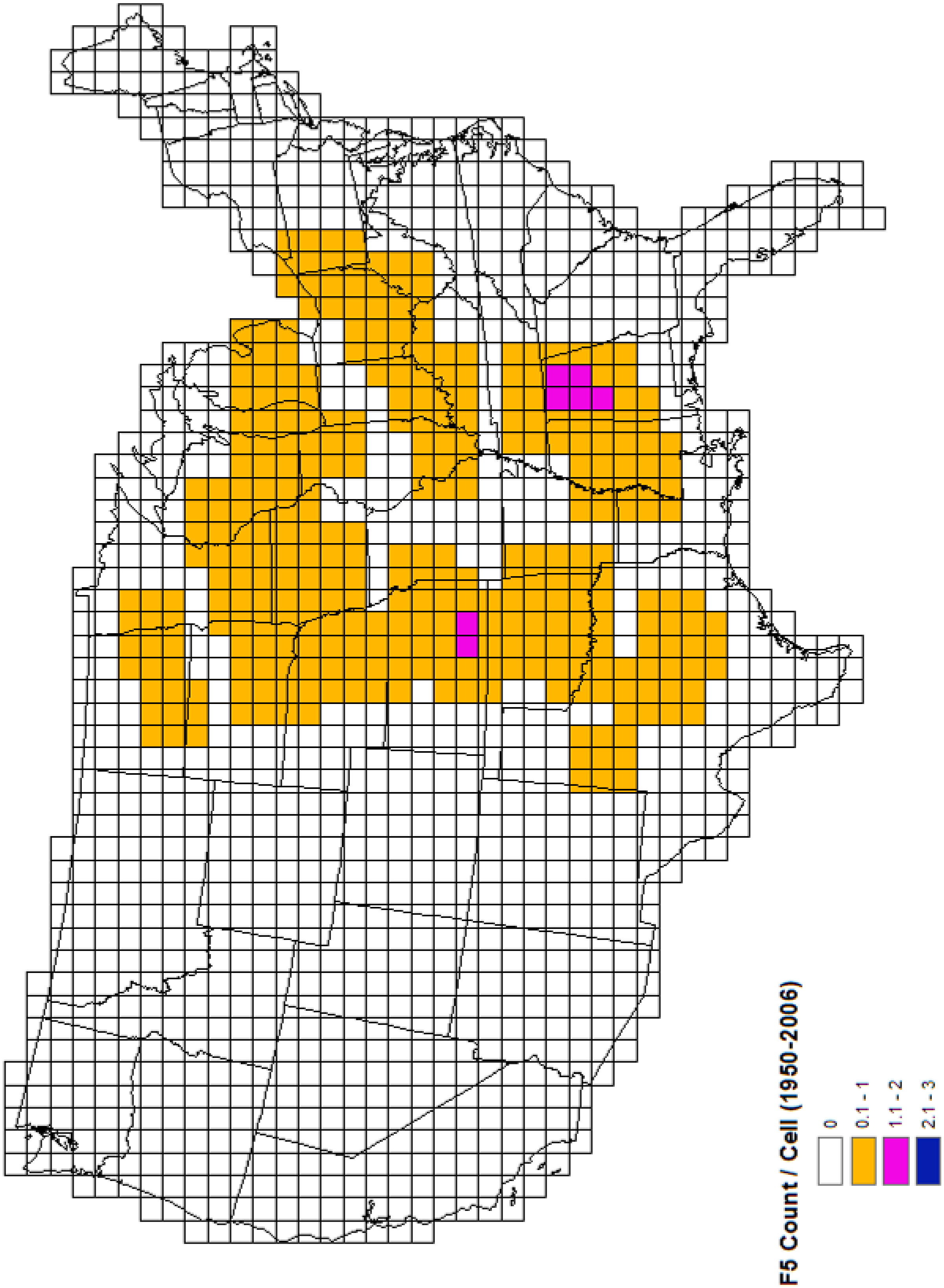

F1 Count / Cell (1950-2006)
0
0.1 - 5
5.1 - 10
10.1 - 20
20.1 - 30
30.1 - 50
50.1 - 87



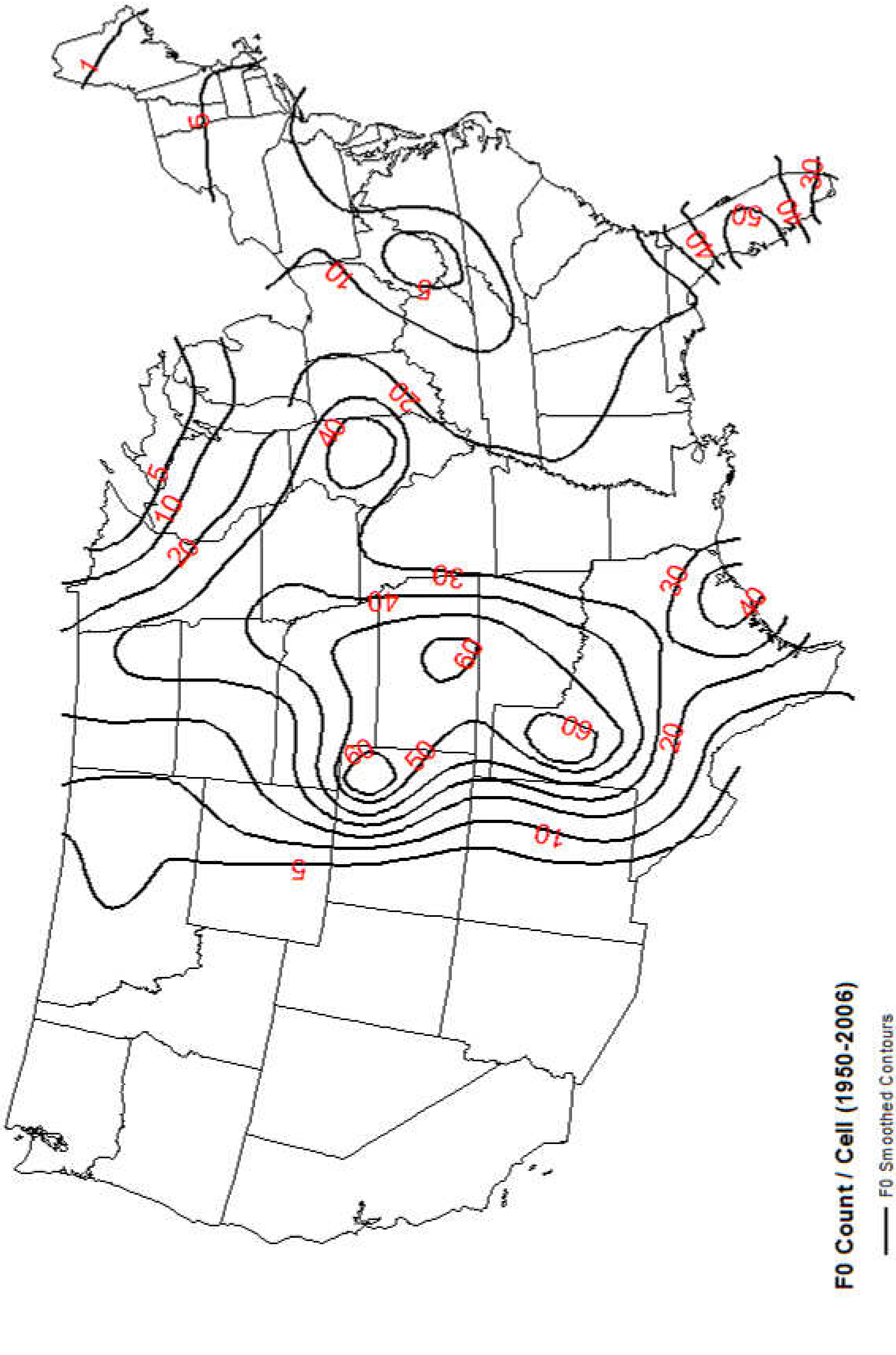
F2 Count / Cell (1950-2006)
0
0.1 - 5
5.1 - 10
10.1 - 15
15.1 - 20
20.1 - 25
25.1 - 50


F3 Count / Cell (1950-2006)
0
0.1 - 1
1.1 - 5
5.1 - 10
10.1 - 15
15.1 - 20
20.1 - 22

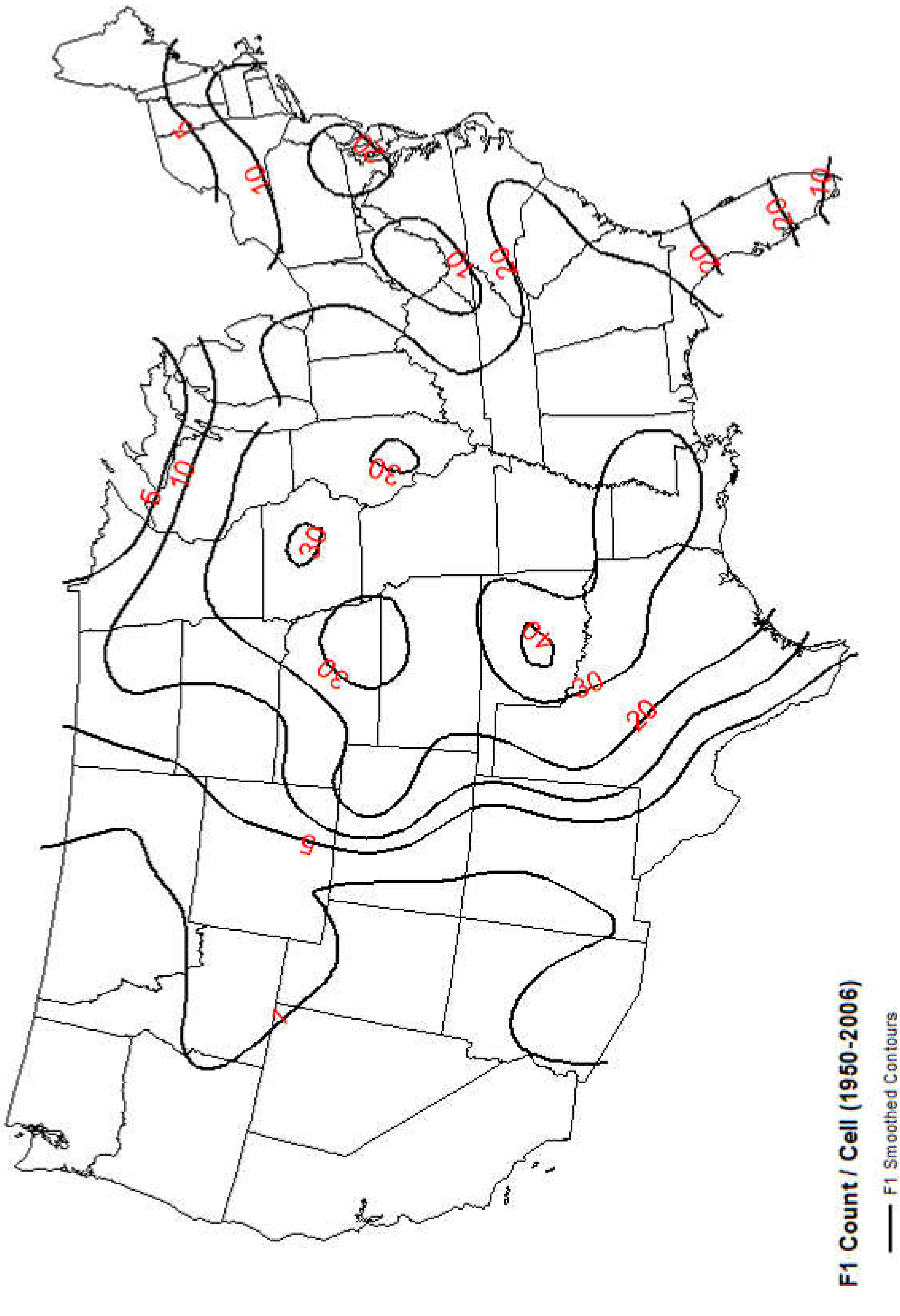

F4 Count / Cell (1950-2006)
0
0.1 - 1
1.1 - 2
2.1 - 3
3.1 - 4
4.1 - 5
5.1 - 7

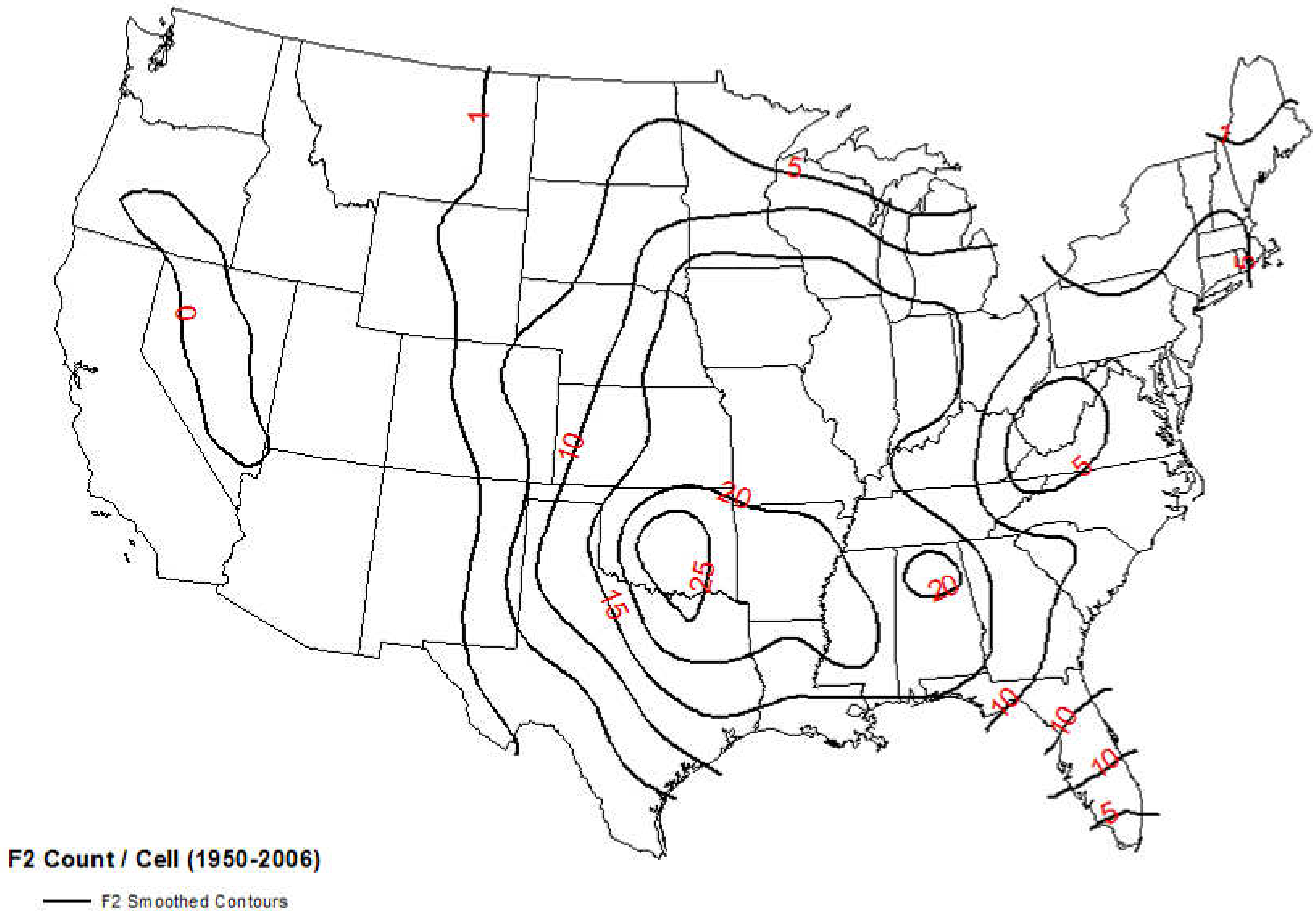

F5 Count / Cell (1950-2006)
0
0.1 - 1
1.1 - 2
2.1 - 3

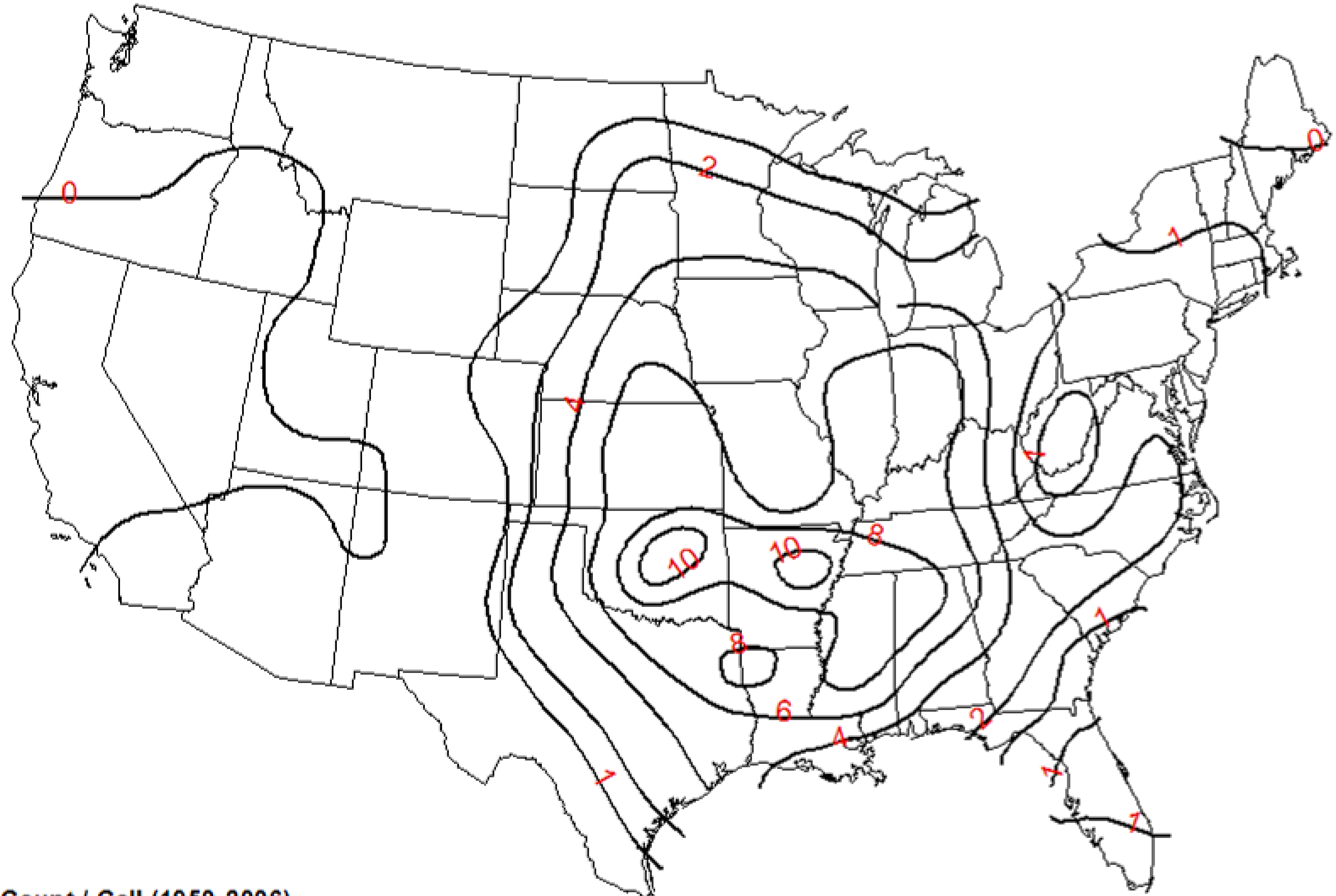
Step 3: Tornado Counts per cell per EF-class Contour Maps



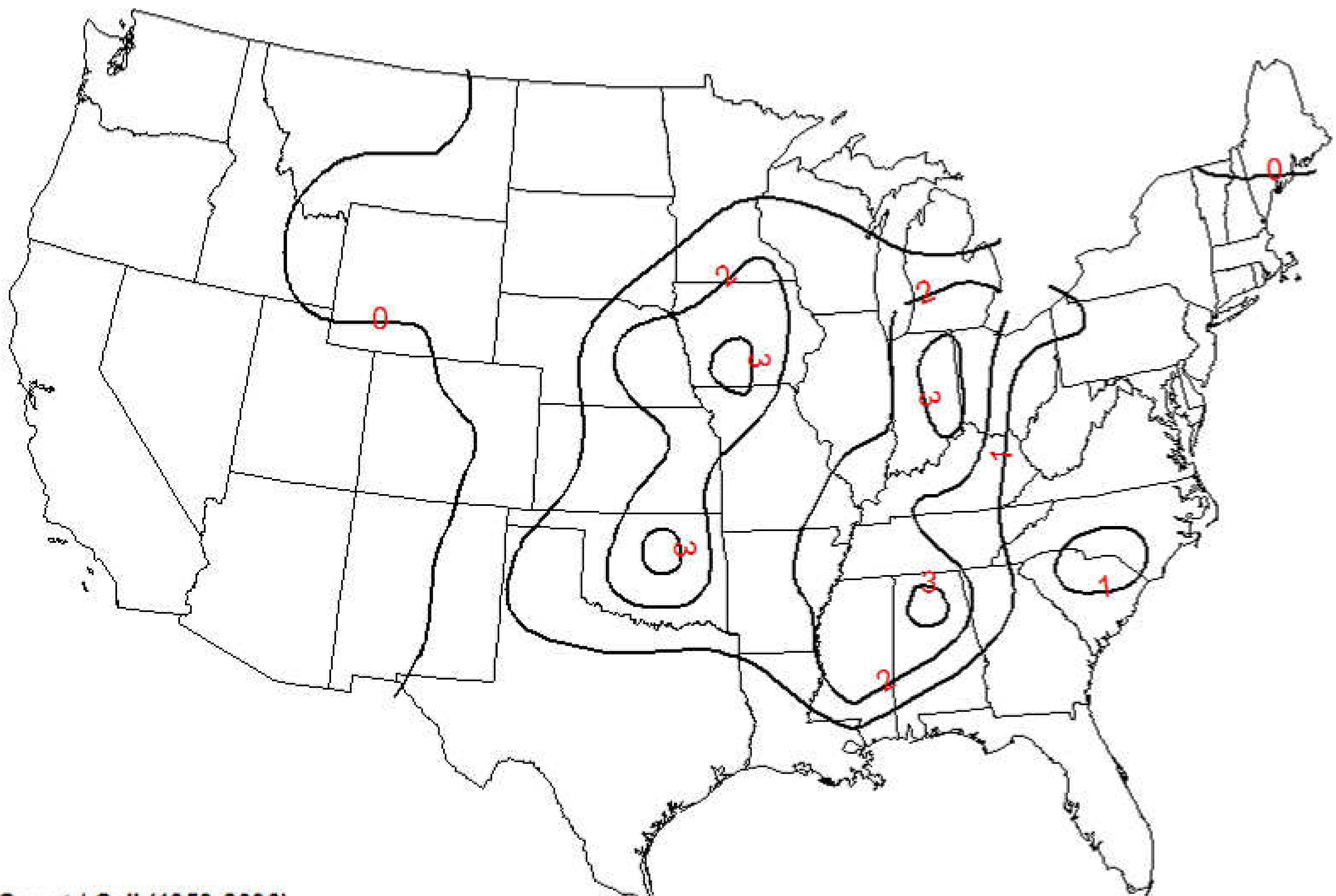
F0 Count / Cell (1950-2006)
F0 Smoothed Contours
1
5
10
20
30
40
50
60


F1 Count / Cell (1950-2006)
F1 Smoothed Contours
1
5
10
20
30
40


1
5
0
10
20
25
15
20
5
10
10
10
5
1
5
F2 Count / Cell (1950-2006)
F2 Smoothed Contours

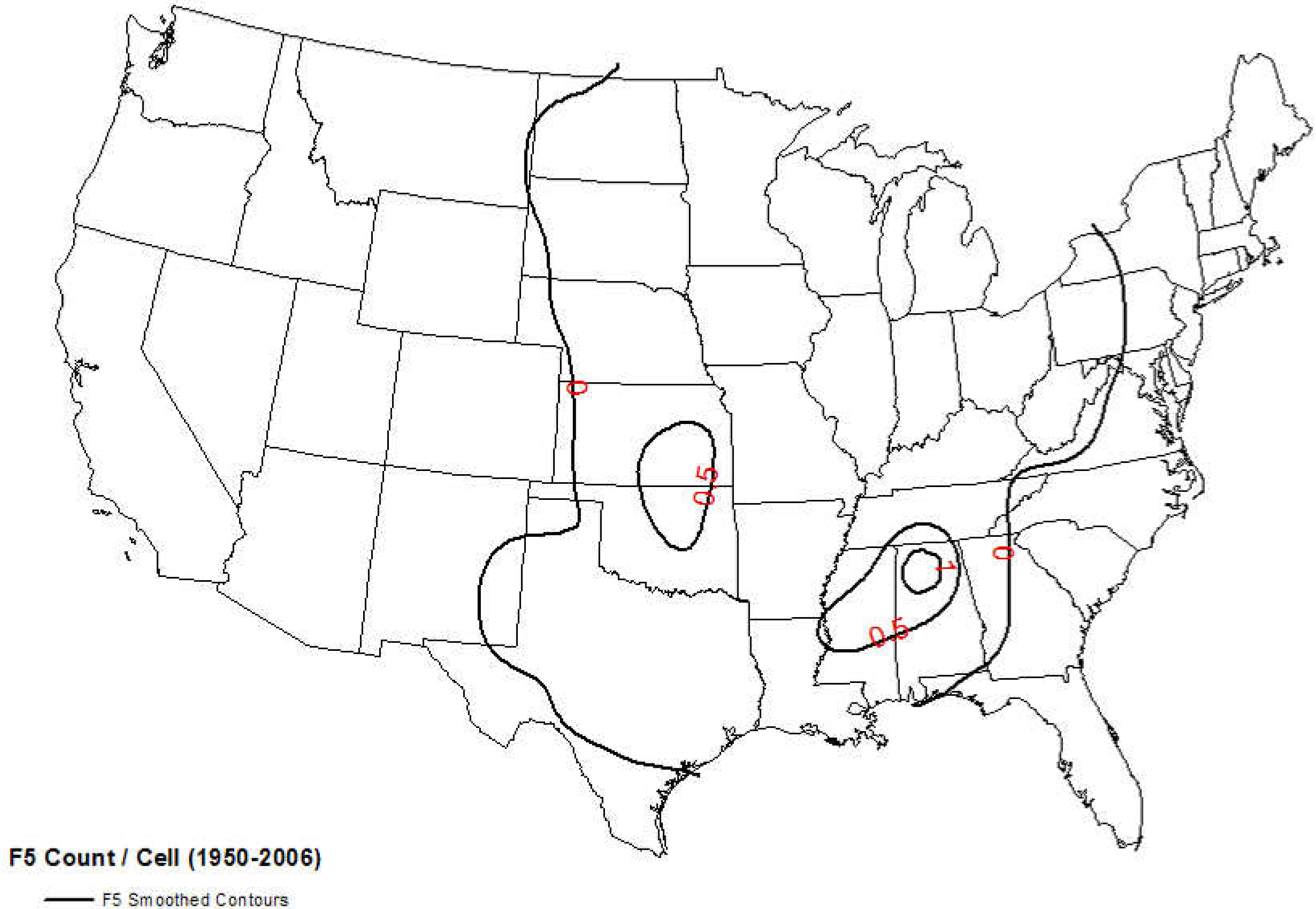


F3 Count / Cell (1950-2006)



F4 Count / Cell (1950-2006)

F4 Smoothed Contours


0
0.5
0.5
1
0
F5 Count / Cell (1950-2006)
F5 Smoothed Contours

Appendix D: Calculation of Injury and Death Tables

The Tornado Expert Panel developed a series of injury and death tables for different structures types, as detailed in Appendix E. These tables were defined in three different ways as follows:

- Structure Damage States
- EF class
- Design Criteria

Those structure types that related to an Enhanced Fujita structure type were defined as shown in Table D-1, where probabilities were assigned for each combination of structure damage state and injury level.

Table D-1. Single Family Residential Injury and Death Table By Structure Damage State

Description	Self treat (%)	Treat & release (%)	Hospitalized (%)	Fatal (%)	EF DOD's	DOD EXP Wind Speed Range (mph)	Calculation Wind Speed (mph)
No damage or very minor	5	5	0	0	1,2	65-79	79
Minor damage	20	20	5	0	3,4	96-97	97
Moderate damage	20	20	10	0	5,6	121-122	122
Severe damage/ partial collapse	30	20	10	5	7	132	132
Total collapse	30	30	20	10	8,9	152-170	170
Complete destruction	10	10	30	50	10	200	200

The "Open" structure type table was defined by EF class, with probabilities assigned for each EF class by injury class (as shown in figure D-2).

Table D-2. Open Injury and Death Table by EF Class

	Self treat (%)	Treat & release (%)	Hospitalized (%)	Fatal (%)
EF0	20	20	5	5
EF1	30	30	15	10
EF2	10	10	30	50
EF3	10	10	30	50
EF4	10	10	30	50
EF5	10	10	30	50

The four safe room design types were defined based on the design wind level, as show in Table D-3 for the Safe Room 160 structure type.

Table D-3. Safe Room 160 Injury and Death Table based on Design Wind Speed

Description	Self treat (%)	Treat & release (%)	Hospitalized (%)	Fatal (%)	Calculation Wind Speed (mph)
Below design	0	0	0	0	<160
At design	5	0	0	0	160
Design plus 20%	10	10	5	0	192
Design plus 40%	10	10	10	5	224

Table D-4 summarizes the basis the expert panel used for all 11 structure types. Please note that the group started out with two school types and later combined them into one structure type.

Table D-4. Injury and Death Table Definition Basis

Structure Type	Injury and Death Table Definition
Open	EF class
Manufactured Housing	Structure Damage States
Small Professional Bldg	Structure Damage States
Metal Bldg	Structure Damage States
Single Family	Structure Damage States
School (K-12)	Structure Damage States
Institutional	Structure Damage States
Safe Room 130	Design Criteria
Safe Room 160	Design Criteria
Safe Room 200	Design Criteria
Safe Room 250	Design Criteria

To use these injury and death tables in the Tornado Module, all the tables need to be converted to the EF class format, where the probability in each injury class is calculated for each EF class, Described below is an example of how the structure damage states and design criteria tables are converted to EF classes. The final tables are all listed in Appendix E.

Step 1: Interpolate values at each EF-class break

Table D-1 shows the example of the injury and death table for single family residential.   Each of the structure damage states shown may have one or several expected wind speeds from the associated degree of damage from the Enhanced Fujita damage tables (also list in Appendix E). Since the panel estimated probabilities based on the worse case scenario for each structure damage state, the greatest expect wind speed for each structure damage state was used to calculate interpolated values. These expected wind speeds are listed in the last column of Table D-1.

Table D-5 listed the wind speeds associated with each of the EF classes.

Table D-5. EF classes and wind speeds (FEMA, Dec 2007)

		EF Scale
Wind Range	**EF Classes**	**3-Second Gust Speed, mph**
1		**0 - 64**
2	EF0	**65 - 85**
3	EF1	**86 - 110**
4	EF2	**111 - 135**
5	EF3	**136 - 165**
6	EF4	**166 - 200**
7	EF5	**>200**

The wind speed breaks between each EF class is interpolated from Table D-1, Table D-6 lists these interpolated wind speeds along with the values from Table D-1 for the hospitalized Injury class. Figure D-1 also shows these values in graphic form.

Table D-6. Calculated hospitalized values for single family residential

Wind Speed (mph)	Hospitalized %	Enhanced Fujita Type
0	0	
65	0	EF0
79	0	EF0
86	1.9	EF1
97	5	EF1
111	7.8	EF2
122	10	EF2
132	10	EF2
136	11.1	EF3
166	18.9	EF4
170	20	EF4
200	30	EF5
>200	30	EF5

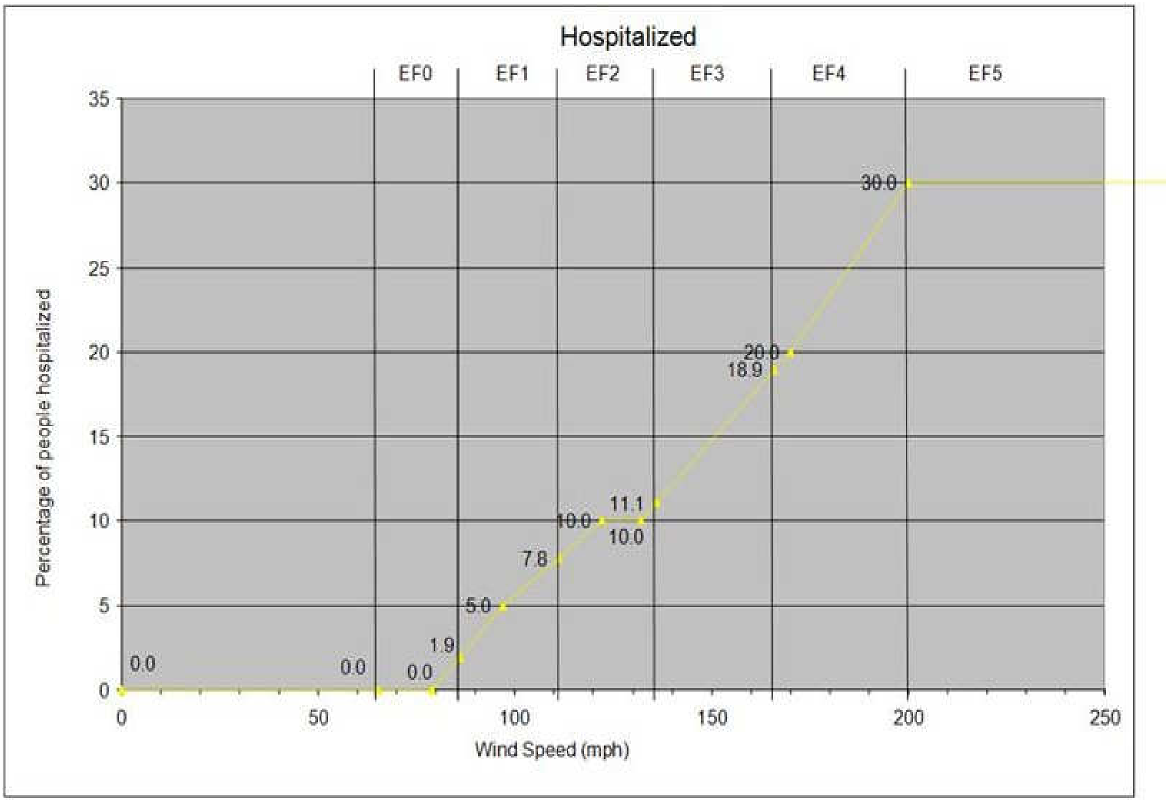


Figure D-1. Single Family Residential Hospitalization Values

Step 2: Calculate average injury probability for each EF-class

For the wind speed ranges for each EF-class, the injury probability is averaged (based on the curve). Table D-7 lists the calculated values for each EF-class. Conceptually, this average value is calculated by determining the area under the line shown in Figure D-1 for each EF class and then dividing by the wind speed range for that EF class.

Table D-7 Calculated hospitalized values for single family residential

EF Classes	Wind Speeds (mph)	Hospitalized (%)
	0 - 64	0
EF0	65 - 85	0
EF1	86 - 110	5
EF2	111 - 135	10
EF3	136 - 165	15
EF4	166 - 200	24
EF5	>200	30

A similar approach is used for the safe room structure types, as shown in Appendix E.

Appendix E: Detailed Injury and Death Tables

OPEN

Worse-case pre-safe room scenario (no protection)

Table E-1 Open Structure Type Injury and Death Table By EF Class

	Self treat (%)	Treat & release (%)	Hospitalized (%)	Fatal (%)
EF0	20	20	5	5
EF1	30	30	15	10
EF2	10	10	30	50
EF3	10	10	30	50
EF4	10	10	30	50
EF5	10	10	30	50

ONE-AND TWO-FAMILY RESIDENCES (FR12)

- (1000 – 5000 square feet)
- Typical Construction
  - Asphalt shingles, tile, slate or metal roof covering
  - Flat, gable, hip, mansard or mono-sloped roof or combinations thereof
  - Plywood/OSB or wood plank roof deck
  - Prefabricated wood trusses or wood joist and rafter construction
  - Brick veneer, wood panels, stucco, EIFS, vinyl or metal siding
  - Wood or metal stud walls, concrete blocks or insulating-concrete panels
  - Attached single or double garage

Table E-2 One and Two Family Structure Type Degree of Damage Table

DOD*	Damage Description	EXP*	LB*	UB*
1	Threshold of visible damage	65	53	80
2	Loss of roof covering material (<20%), gutters and/or awning; loss of vinyl or metal siding	79	63	97
3	Broken glass in doors and windows	96	79	114
4	Uplift of roof deck and loss of significant roof covering material (>20%); collapse of chimney; garage doors collapse inward; failure of porch or carport	97	81	116
5	Entire house shifts off foundation	121	103	141
6	Large sections of roof structure removed; most walls remain standing	122	104	142
7	Exterior walls collapsed	132	113	153
8	Most walls collapsed, except small interior rooms	152	127	178
9	All walls	170	142	198
10	Destruction of engineered and/or well constructed residence; slab swept clean	200	165	220

DOD is degree of damage, EXP is Expected Wind Speed (mph), LB is lower boundary wind speed (mph), UB is upper boundary wind speed (mph). See Wind Science and Engineering Center (2006) for more detailed definitions.

Table E-3 One and Two Family Structure Type Injury and Death Table by Structure Damage State

Description	Self treat (%)	Treat & release (%)	Hospitalized (%)	Fatal (%)	EF DOD's	DOD EXP Wind Speed Range (mph)	Calculation Wind Speed (mph)
No damage or very minor	5	5	0	0	1,2	65-79	79
Minor damage	20	20	5	0	3,4	96-97	97
Moderate damage	20	20	10	0	5,6	121-122	122
Severe damage/ partial collapse	30	20	10	5	7	132	132
Total collapse	30	30	20	10	8,9	152-170	170
Complete destruction	10	10	30	35	10	200	200

Table E-4 One and Two Family Structure Type Injury and Death Table by EF Class

	Self treat (%)	Treat & release (%)	Hospitalized (%)	Fatal (%)
EF0	4	4	0	0
EF1	18	18	5	0
EF2	24	20	10	2
EF3	30	25	15	8
EF4	21	21	24	21
EF5	10	10	30	35

MANUFACTURED HOME – DOUBLE WIDE (MHDW)

Typical Construction

- Steel undercarriage supported on concrete block piers
- Metal straps and ground anchors (frame and/or over-the-top strap anchors)
- Asphalt shingles or one-piece metal roof covering
- Wood roof joists
- Metal, vinyl, or wood siding
- Wood stud walls and partitions
- Better construction in post 1974 models in coastal areas

Table E-5 Manufactured Home Structure Type Degree of Damage Table

DOD*	Damage Description	EXP*	LB*	UB*
1	Threshold of visible damage	61	51	76
2	Loss of shingles or partial uplift of one-piece metal roof covering	74	61	92
3	Unit slides of block piers but remains upright	87	72	102
4	Complete uplift of roof; most walls remain standing	89	73	112
5	Unit rolls on its side or upside down; remains essentially intact	98	84	114
6	Destruction of roof and walls leaving floor and undercarriage in place	105	87	123
7	Unit rolls or vaults; roof and walls separate from floor and undercarriage	109	96	128
8	Undercarriage separates from unit; rolls, tumbles, and is badly bent	118	101	136
9	Complete destruction unit; debris blown away	127	110	148

*DOD is degree of damage, EXP is Expected Wind Speed (mph), LB is lower boundary wind speed (mph), UB is upper boundary wind speed (mph). See Wind Science and Engineering Center (2006) for more detailed definitions.

Table E-6 Manufactured Home Structure Type Injury and Death Table by Structure Damage State

Description	Self treat (%)	Treat & release (%)	Hospitalized (%)	Fatal (%)	EF DOD's	DOD EXP Wind Speed Range (mph)	Calculation Wind Speed (mph)
No damage or very minor	5	5	0	0	1,2	61-74	74
Minor damage	20	20	5	0	3	87	87
Moderate damage	20	20	10	0	4	89	89
Severe damage/ partial collapse	30	30	10	5	5	98	98
Total collapse	30	30	20	10	6	105	105
Complete destruction	10	10	30	50	7,8,9	109-127	127

Table E-7 Manufactured Home Structure Type Injury and Death Table by EF Class

	Self treat (%)	Treat & release (%)	Hospitalized (%)	Fatal (%)
EF0	8	8	1	0
EF1	26	26	14	7
EF2	15	15	28	41
EF3	10	10	30	50
EF4	10	10	30	50
EF5	10	10	30	50

METAL BUILDING SYSTEM (MBS)

Typical Construction

- Examples are warehouses, industrial facilities, and small areas
- Metal panel walls and standing seam roof
- Nearly all have a gable roof and relatively tall walls
- Large overhead doors
- Large-span single bay rigid frames
- Z or C-shaped purlins and girts span between rigid frames
- Lateral loads resisted by x-bracing in direction parallel to ridge
- Relatively weak end-wall frames

Table E-8 Metal Building Structure Type Degree of Damage Table

DOD*	Damage Description	EXP*	LB*	UB*
1	Threshold of visible damage	67	54	83
2	Inward or outward collapse of overhead doors	89	75	108
3	Metal roof or wall panels pulled from the building	95	78	120
4	Column anchorage failed	117	96	135
5	Buckling of roof purlins	118	95	138
6	Failure of X-braces in the lateral load resisting system	138	118	158
7	Progressive collapse of rigid frames	143	120	168
8	Total destruction of building	155	132	178

* DOD is degree of damage, EXP is Expected Wind Speed (mph), LB is lower boundary wind speed (mph), UB is upper boundary wind speed (mph). See Wind Science and Engineering Center (2006) for more detailed definitions.

Table E-9 Metal Building Structure Type Injury and Death Table by Structure Damage State

Description	Self treat (%)	Treat & release (%)	Hospitalized (%)	Fatal (%)	EF DOD's	DOD EXP Wind Speed Range (mph)	Calculation Wind Speed (mph)
No damage or very minor	5	0	0	0	1	67	67
Minor damage	10	5	5	0	2	89	89
Moderate damage	10	10	5	5	3	95	95
Severe damage/ partial collapse	20	10	10	5	4,5,6	117-138	138
Total collapse	10	30	20	10	7	143	143
Complete destruction	20	20	30	30	8	155	155

Table E-10 Metal Building Structure Type Injury and Death Table by EF Class

	Self treat (%)	Treat & release (%)	Hospitalized (%)	Fatal (%)
EF0	7	2	2	0
EF1	11	9	6	4
EF2	17	10	8	5
EF3	17	21	24	21
EF4	20	20	30	30
EF5	20	20	30	30

SMALL PROFESSIONAL BUILDING (SPB)

Single story, less than 5000 square feet

Typical Construction

- Flat, gable, hip, mansard or mono-slope roofs with or without parapet walls
- Asphalt shingles, tile, slate, metal panels, single ply or built up roof covering
- Light-frame steel construction, steel joists, and formed metal decking
- Load-bearing masonry construction with steel or wood floor structure
- Timber post and beam construction
- Wood or metal stud walls, non-bearing masonry walls
- Metal or vinyl panels, stucco or EIFS cladding
- Skylights and/or clearstories

Table E-11 Small Professional Building Structure Type Degree of Damage Table

DOD*	Damage Description	EXP*	LB*	UB*
1	Threshold of visible damage	65	54	81
2	Loss of roof covering (<20%)	78	65	98
3	Broken windows including clear story windows or skylights	89	74	107
4	Exterior doors fail	100	82	118
5	Uplift of roof decking; significant loss of roof covering (>20%); loss of roof HVAC equipment	100	84	117
6	Collapsed façade or parapet walls	103	85	123
7	Uplift or collapse of entire roof structure	124	105	145
8	Collapse of exterior walls; closely spaced interior walls remain standing	144	123	165
9	Total destruction of entire building	157	148	200

* DOD is degree of damage, EXP is Expected Wind Speed (mph), LB is lower boundary wind speed (mph), UB is upper boundary wind speed (mph). See Wind Science and Engineering Center (2006) for more detailed definitions.

Table E-12 Small Professional Building Structure Type Injury and Death Table by Structure Damage State

Description	Self treat (%)	Treat & release (%)	Hospitalized (%)	Fatal (%)	EF DOD's	DOD EXP Wind Speed Range (mph)	Calculation Wind Speed (mph)
No damage or very minor	5	5	0	0	1,2	65-78	78
Minor damage	20	20	5	0	3	89	89
Moderate damage	20	20	10	5	4,5,6	100-103	103
Severe damage/ partial collapse	10	25	25	15	7	124	124
Total collapse	10	20	30	30	8	144	144
Complete destruction	10	10	30	50	9	157	157

Table E-13 Small Professional Building Structure Type Injury and Death Table by EF Class

	Self treat (%)	Treat & release (%)	Hospitalized (%)	Fatal (%)
EF0	6	6	1	0
EF1	19	20	9	4
EF2	12	23	23	16
EF3	10	15	30	40
EF4	10	10	30	50
EF5	10	10	30	50

Schools (K-12): Based on JUNIOR OR SENIOR HIGH SCHOOLS (JHSH)

General Description

- Generally large one or two-story buildings with flat roofs
- May contain gymnasiums, cafeteria and auditorium with large structural spans; may have a basement
- Classroom wings have interior hallways with bearing or non-bearing interior walls
- BUR or single-ply membrane roof covering with or without gravel
- Structural system may consist of an all steel structure or an all reinforced concrete structure or a combination of both
- Roof structure may be light steel construction with open web joists supported on steel beams; corrugated metal roof deck with rigid insulation or poured gypsum deck
- Exterior walls constructed of concrete or clay blocks with brick veneer, stucco or EIFS; metal and glass curtain walls; walls may have more than 30% windows

Table E-14 Schools Structure Type Degree of Damage Table

DOD*	Damage Description	EXP*	LB*	UB*
1	Threshold of visible damage	68	55	83
2	Loss of roof covering (<20%)	79	66	99
3	Broken windows	87	71	106
4	Exterior door failures	101	83	121
5	Uplift of metal roof decking; significant loss of roofing material (>20%); loss of rooftop HVAC	101	85	119
6	Damage to or loss of wall cladding	108	92	127
7	Collapse of tall masonry walls at gym, cafeteria or auditorium	114	94	136
8	Uplift or collapse of light steel roof structure	125	108	148
9	Collapse of exterior walls in top floor	139	121	153
10	Most interior walls of top floor collapsed	158	133	186
11	Complete destruction of all or a large section of building	192	163	224

* DOD is degree of damage, EXP is Expected Wind Speed (mph), LB is lower boundary wind speed (mph), UB is upper boundary wind speed (mph). See Wind Science and Engineering Center (2006) for more detailed definitions.

Table E-15 Schools Structure Type Injury and Death Table by Structure Damage State

Description	Self Treat (%)	Treat & release (%)	Hospitalized (%)	Fatal (%)	EF DOD's	DOD EXP Wind Speed Range (mph)	Calculation Wind Speed (mph)
no damage or very minor	5	5	0	0	1,2	68-79	79
minor damage	20	20	5	0	3	87	87
moderate damage	20	20	10	5	4,5,6	101-108	108
severe damage/ partial collapse	20	25	15	10	7,8,9	114-139	139
total collapse	25	30	20	15	10	158	158
complete destruction	10	25	30	35	11	192	192

Table E-16 Schools Structure Type Injury and Death Table by EF Class

	Self treat (%)	Treat & release (%)	Hospitalized (%)	Fatal (%)
EF0	6	6	1	0
EF1	20	20	8	3
EF2	20	23	13	8
EF3	22	28	18	14
EF4	14	26	27	29
EF5	10	25	30	35

INSTITUTIONAL BUILDING (IB)

General Description

- Examples are hospitals, courthouses, university buildings, state and federal buildings, jails
- Range in height from 1 – 10 stories
- Roofing materials include fully adhered and mechanically fastened single-ply membranes, polyurethane foam, copper clad domes
- Structure is normally reinforced concrete
- Walls are masonry with cut stone or precast panels – very ornate
- Balcones, porches and porticos with heavy façade
- Relatively small windows

Table E-17 Institutional Building Structure Type Degree of Damage Table

DOD*	Damage description	EXP*	LB*	UB*
1	Threshold of visible damage	72	59	88
2	Loss of roof covering (<20%)	86	72	109
3	Damage to penthouse roof and walls; loss of rooftop HVAC equipment	92	75	111
4	Broken glass in windows or doors	95	78	115
5	Uplift of lightweight roof deck and insulation; significant loss of roofing material (>20%)	114	95	136
6	Façade components torn from structure	118	97	140
7	Damage curtain walls or other wall cladding	131	110	152
8	Uplift of pre-cast concrete roof slabs	142	119	163
9	Uplift of metal deck with concrete fill slab	146	118	170
10	Collapse of some top story exterior walls	148	127	172
11	Complete destruction of all or a large portion of building	210	178	268

* DOD is degree of damage, EXP is Expected Wind Speed (mph), LB is lower boundary wind speed (mph), UB is upper boundary wind speed (mph). See Wind Science and Engineering Center (2006) for more detailed definitions.

Table E-18 Institutional Building Structure Type Injury and Death Table by Structure Damage State

Description	Self Treat (%)	Treat & release (%)	Hospitalized (%)	Fatal (%)	EF DOD's	DOD EXP Wind Speed Range (mph)	Calculation Wind Speed (mph)
no damage or very minor	5	0	0	0	1,2	72-86	86
minor damage	10	5	5	0	3,4	92-95	95
moderate damage	10	10	5	0	5,6	114-118	118
severe damage/ partial collapse	10	10	10	5	7,8,9	131-146	146
total collapse	10	10	10	5	10	148	148
complete destruction	10	10	20	10	11	210	210

Table E-19 Institutional Building Structure Type Injury and Death Table by EF Class

	Self Treat (%)	Treat & release (%)	Hospitalized (%)	Fatal (%)
EF0	2	0	0	0
EF1	9	5	4	0
EF2	10	10	6	1
EF3	10	10	11	5
EF4	10	10	16	8
EF5	10	10	20	10

Table E-20 Safe Room 130 MPH Structure Type Injury and Death Table based on Design Wind Speed

Description	Self treat (%)	Treat & release (%)	Hospitalized (%)	Fatal (%)	Calculation Wind Speed (mph)
Below design	0	0	0	0	<130
At design	5	0	0	0	130
Design plus 20%	10	10	5	0	156
Design plus 40%	10	10	10	5	182

Table E-21 Safe Room 130 MPH Structure Type Injury and Death Table by EF Class

	Self treat (%)	Treat & release (%)	Hospitalized (%)	Fatal (%)
EF0	0	0	0	0
EF1	0	0	0	0
EF2	1	0	0	0
EF3	9	7	4	0
EF4	10	10	9	4
EF5	10	10	10	5

Table E-22 Safe Room 160 MPH Structure Type Injury and Death Table based on Design Wind Speed

Description	Self treat (%)	Treat & release (%)	Hospitalized (%)	Fatal (%)	Calculation Wind Speed (mph)
Below design	0	0	0	0	<160
At design	5	0	0	0	160
Design plus 20%	10	10	5	0	192
Design plus 40%	10	10	10	5	224

Table E-23 Safe Room 160 MPH Structure Type Injury and Death Table by EF Class

	Self treat (%)	Treat & release (%)	Hospitalized (%)	Fatal (%)
EF0	0	0	0	0
EF1	0	0	0	0
EF2	0	0	0	0
EF3	1	0	0	0
EF4	8	7	4	0
EF5	10	10	10	5

Table E-24 Safe Room 200 MPH Structure Type Injury and Death Table based on Design Wind Speed

Description	Self treat (%)	Treat & release (%)	Hospitalized (%)	Fatal (%)	Calculation Wind Speed (mph)
Below design	0	0	0	0	<200
At design	5	0	0	0	200
Design plus 20%	10	10	5	0	240
Design plus 40%	10	10	10	5	280

Table E-25 Safe Room 200 MPH Structure Type Injury and Death Table by EF Class

	Self treat (%)	Treat & release (%)	Hospitalized (%)	Fatal (%)
EF0	0	0	0	0
EF1	0	0	0	0
EF2	0	0	0	0
EF3	0	0	0	0
EF4	0	0	0	0
EF5	9	9	7	3

Table E-26 Safe Room 250 MPH Structure Type Injury and Death Table based on Design Wind Speed

Description	Self treat (%)	Treat & release (%)	Hospitalized (%)	Fatal (%)	Calculation Wind Speed (mph)
Below design	0	0	0	0	<250
At design	5	0	0	0	250
Design plus 20%	10	10	5	0	300
Design plus 40%	10	10	10	5	350

Table E-27 Safe Room 250 MPH Structure Type Injury and Death Table by EF Class

	Self treat (%)	Treat & release (%)	Hospitalized (%)	Fatal (%)
EF0	0	0	0	0
EF1	0	0	0	0
EF2	0	0	0	0
EF3	0	0	0	0
EF4	0	0	0	0
EF5	6	5	3	1